POLITECNICO DI TORINO

III Facoltà di Ingegneria

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Tesi di Laurea Magistrale

Athlete DSS and data analysis

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Sommario

Il lavoro che viene presentato si pone l'obiettivo di illustrare in dettaglio l'attività svolta durante il periodo di tesi presso la UPC (Universitat Politècnica de Catalunya) ed analizzare gli aspetti teorici che la supportano.

Il lavoro di tesi riguarda la collaborazione allo sviluppo del progetto denominato *+Atleta*. Lo scopo di tale progetto è quello di realizzare un DSS (Decision Support System) in ambito sportivo; tale software avrà la funzione di monitorare le prestazioni di un elevato numero di atleti fornendo l'analisi approfondita dei dati, al fine di perseguire il miglioramento del rendimento sportivo degli atleti stessi. Partendo dall'analisi dei parametri biologici, il software sarà inoltre in grado di simulare le prestazioni future degli atleti.

Il lavoro svolto è stato incentrato sullo sviluppo del progetto esistente e sull'aggiunta di nuove funzionalità al programma. Il progetto +Atleta, che prese il via nel 2005, si trova nella fase di ultimazione dell'intera infrastruttura del sistema, grazie alla quale si potranno eseguire in futuro le simulazioni di prestazioni. Per raggiungere questo obiettivo, devono essere presi in considerazione numerosi fattori: i parametri biologici dell'atleta, i dati relativi ad ogni gara od allenamento, le condizioni meteorologiche e quelle ambientali.

Scendendo nel dettaglio, sono stati studiati ed implementati algoritmi di analisi dei dati relativamente allo sforzo fisico dell'atleta, al profilo altimetrico della corsa ed alle caratteristiche topografiche del percorso di gara. Ciò ha determinato la creazione di numerose viste statistiche (suddivise per categoria) e l'analisi di alcuni fattori mediante la regressione lineare. Il lavoro è iniziato con lo studio del sistema preesistente e, passando attraverso lo studio della struttura di analisi dei dati, si è concluso con l'implementazione

delle nuove funzionalità. Nel presente documento saranno pertanto descritti gli obiettivi, le scelte progettuali e le implementazioni realizzate durante il periodo di lavoro di tesi. Al termine verranno riportate le conclusioni con relative considerazioni finali.

1.1 Introduzione

Attualmente, nel mondo dello sport, la competitività a livello professionistico è talmente alta che si ricerca l'aiuto di qualsiasi strumento per migliorare le prestazioni ed il rendimento di un atleta. Negli ultimi anni, si fa sempre più ricorso alla tecnologia, in quanto ci si è resi conto che il suo impiego nelle diverse discipline sportive ha avuto come conseguenza il miglioramento dei risultati ottenuti in precedenza. Si è arrivati al punto, a livello professionistico, che un qualsivoglia margine di miglioramento, per quanto piccolo possa essere, possa tramutarsi nel superamento dell'attuale record mondiale oppure, più semplicemente, in una vittoria.

L'uomo, per sua natura, è molto competitivo e tende a migliorarsi ed a superare se stesso ed i propri limiti, giorno dopo giorno. Per raggiungere questo obiettivo è obbligato a tenere sempre sotto osservazione quei parametri che lo portano a incrementare le proprie prestazioni, in modo da poter lavorare sempre con la massima efficienza. Per questo motivo, esiste oggi un gran numero di aziende, spesso multinazionali, che già da anni puntano molto su progetti di questo tipo. Lo spettro delle possibili attività è piuttosto ampio e variegato: alcuni produttori si occupano della strumentazione professionale in grado di rilevare i parametri biologici dell'atleta, certe aziende offrono servizi di analisi dei dati raccolti come supporto alle decisioni in merito allo stato fisico di un soggetto, altre aziende ancora si preoccupano di produrre l'abbigliamento sportivo più adatto alla disciplina praticata. Oltre a ciò, si è assistito alla istituzione di numerosi centri sportivi specializzati in questo campo, di norma al servizio di società sportive di grande rilievo, nei quali viene impiegata tecnologia all'avanguardia e personale altamente qualificato per perseguire lo scopo del miglioramento delle prestazioni sportive degli atleti.

All'interno di questo complesso scenario è nato presso la UPC (Universitat Politècnica

de Catalunya) di Barcellona il progetto denominato *+Atleta*. Tale progetto, curato dal Professor Pau Fonseca i Casas, si colloca nell'ambito dell'analisi dei dati sportivi. +Atleta è stato ideato a seguito di una lunga ed approfondita analisi relativamente ai prodotti esistenti sul mercato. Detta ricerca ne ha preso in esame le caratteristiche, i punti forti e quelli deboli, al fine di evidenziarne i limiti, le carenze e tutte le future possibilità di sviluppo. Sono stati presi come modello per l'analisi le aziende leader in questo settore; in particolare si tratta di tre aziende di rilievo internazionale: POLAR, GARMIN e SUUNTO. Tali imprese producono pulsometri professionali e forniscono al cliente software proprietari che, una volta installati sul proprio PC, provvedono a visualizzare e gestire i dati raccolti durante una gara od una qualsiasi sessione di allenamento. I parametri biologici raccolti, non subiscono tuttavia profonde analisi, ma nella maggior parte dei casi vengono solamente mostrati all'utente sotto forma di grafico o di tabella. Ciò significa che, rispetto alle informazioni che il pulsometro stesso fornisce in tempo reale durante il periodo di attività fisica, il software non introduce sostanziali novità, se non quella di mostrare i dati in forma più leggibile. Inoltre, l'utente deve necessariamente utilizzare il software fornito dalla ditta costruttrice dell'apparecchio che ha acquistato, poiché ciascuna impresa utilizza un formato di dati proprietario. Questo fattore costituisce uno svantaggio non indifferente, poiché con lo stesso programma non è possibile visualizzare dati provenienti da strumenti di marche distinte.

A seguito di tali considerazioni, si inserisce l'idea di creare uno strumento nuovo, nato dall'esigenza di ovviare alle carenze di quelli esistenti, per superarne le limitazioni e proporsi come alternativa, in particolar modo per quanto riguarda l'uso professionale. Il progetto +Atleta si propone dunque come strumento in grado di offrire caratteristiche e funzionalità nuove nel settore dell'analisi dei dati biologici. Esso prese il via nel settembre del 2005 e si trova tuttora in fase di sviluppo. Tale progetto, di durata pluriennale, ha come obiettivo quello di creare un DSS (Decision Support System), un software molto complesso, in grado di permettere il monitoraggio costante e dettagliato delle prestazioni sportive di un elevato numero di atleti e l'analisi approfondita dei dati raccolti, al fine di perseguire il miglioramento del rendimento sportivo degli atleti stessi. Attraverso l'analisi

di una grande quantità di dati, il DSS si comporterà come un vero e proprio sistema di simulazione, con l'obiettivo di prevedere in anticipo le prestazioni future di un atleta in una particolare disciplina, su uno specifico tracciato, con particolari condizioni atmosferiche ed ambientali.

+Atleta si propone di creare un prodotto nuovo rispetto a quelli oggigiorno in commercio. Le carenze dei prodotti presenti sul mercato divengono dunque i punti di forza di questo progetto. Facendo uso dei pulsometri delle già citate case costruttrici, il software +Atleta è concepito per essere uno strumento standard, in grado cioè di acquisire ed elaborare dati provenienti da qualsivoglia strumento, indipendentemente dalla marca o dal modello di quest'ultimo. I dati raccolti vengono tradotti e mappati in un file in formato standard XML (si veda il paragrafo 2.4.3) e successivamente salvati in un database MySQL. Da un lato i dati vengono visualizzati all'utente sotto forma di grafico o di tabella, in maniera tale da far risaltare quelli più importanti e significativi; dall'altro subiscono elaborazioni più complesse al fine di calcolare numerosi parametri biologici utili per monitorare e migliorare delicati aspetti della preparazione atletica. Tali parametri biologici, ricavati da calcoli effettuati sui dati originari in ingresso, rappresentano fattori e variabili che verranno immessi come input nel DSS ed andranno dunque ad incidere nella simulazione delle prestazioni di un atleta.

La presente Tesi di laurea si occupa di descrivere il lavoro di collaborazione ed il ruolo assunto dal sottoscritto nello sviluppo del progetto +Atleta. Per volgere al termine, il progetto +Atleta prevede il completamento di numerose ed elaborate fasi di lavoro; esse sono state descritte nel paragrafo 2.1 (Project planning) e sono state pianificate in maniera tale da poter essere svolte da più studenti contemporaneamente. Una fase propedeutica del lavoro di tesi è stata dedicata allo studio dell'architettura, del funzionamento e della direzione degli sviluppi relativi al il progetto esistente. Lo spettro delle attività da svolgere è piuttosto complesso, tanto da coinvolgere studenti con formazioni universitarie e competenze diverse dall'ingegneria. L'attività svolta si colloca nella fase di ultimazione dell'infrastruttura del sistema esistente, illustrato in ogni sua parte nel capitolo 2. Nello svolgimento del lavoro sono state affrontate due principali tematiche: la prima consiste

nella creazione della struttura atta ad effettuare l'analisi statistica dei dati mediante l'interfacciamento con il software R; previa una fase di studio del funzionamento e delle potenzialità del software R, l'attenzione è stata rivolta all'implementazione della regressione lineare, analisi statistica che offre interessanti informazioni sullo stato fisico dell'atleta. Tuttavia lo scopo principale di questo lavoro è stato quello di documentare la creazione della struttura, descrivere i procedimenti ed i meccanismi del collegamento tra +Atleta ed il software statistico, affinché ricercatori futuri, in possesso di buone competenze di medicina sportiva, possano utilizzarla per analisi mirate, più efficienti e più complesse. Il lavoro relativamente a questa parte è descritto nel capitolo 3. La seconda tematica affrontata riguarda invece l'ideazione di tre algoritmi di analisi di dati relativamente allo sforzo fisico dell'atleta, al profilo altimetrico del percorso di gara ed alla planimetria della corsa. Tali algoritmi hanno lo scopo di visualizzare statistiche relative al proprio ambito e calcolare alcuni parametri che, come predetto, potranno essere utilizzati come input per il simulatore. La teoria ed il funzionamento di tali algoritmi è dettagliatamente illustrata nel capitolo 4. La parte successiva, affrontata nel capitolo 5 della Tesi, riguarda l'implementazione vera e propria di tali algoritmi mediante l'utilizzo dell'ambiente di sviluppo Visual Studio 2005 della Microsoft © e del linguaggio di programmazione Visual C++. Inoltre, si è realizzata un'adeguata interfaccia utente attraverso la quale è possibile disporre agevolmente di tutte le funzionalità aggiunte al software +Atleta. Sono esposte infine le caratteristiche, le scelte progettuali effettuate, l'organizzazione delle classi implementate, i diagrammi dei casi d'uso ed i diagrammi di sequenza propri del progetto di ingegneria del software. L'ultimo capitolo (6) riporta le conclusioni sul lavoro svolto, la descrizione dello stato attuale del progetto e le ipotesi sugli sviluppi futuri.

1.2 Descrizione del sistema esistente

Il seguente schema illustra le connessioni esistenti tra gli elementi che compongono il sistema ed il flusso di dati scambiato:

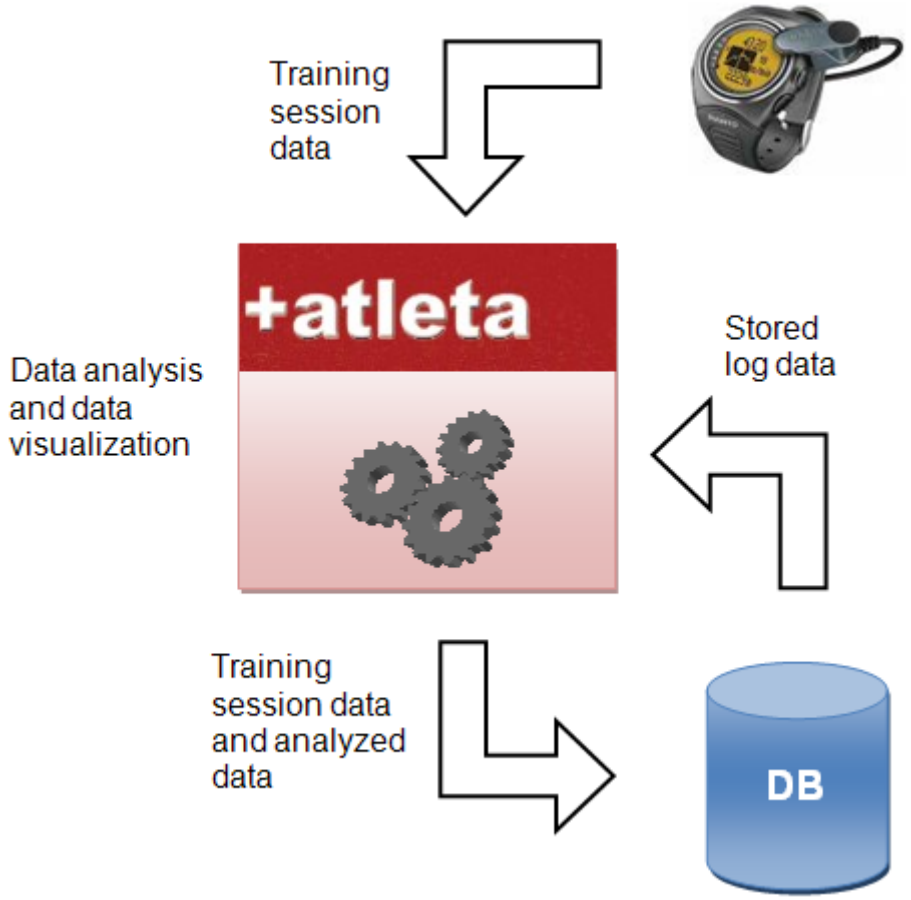


Figura 1.1. Elementi del sistema

Come illustra la figura, il sistema è composto essenzialmente da tre parti:

- **base di dati:** contiene i dati relativi a tutti gli atleti e agli allenatori; la grande maggioranza dei dati è rappresentata delle informazioni generate automaticamente dai pulsometri. Solamente una minima parte è inserita manualmente dell'utente;

ulteriori dati, in numero decisamente inferiore, provengono dalle elaborazioni del programma sui dati originali.

- **Software +Atleta:** permette all'utente di avere una visione completa dei suoi dati di allenamento o di gara; tali dati possono essere piani di allenamento, viste grafiche dei parametri fisiologici oppure dati completi sulle corse. I dati sono analizzati dal software per ricavare parametri più complessi e specifici. Il software gestisce la connessione sia con il database che con i dispositivi esterni.

- **Pulsometro:** origina la maggior parte dei dati presenti nel database; essi sono i dati immagazzinati durante ogni gara od allenamento.

1.2.1 La base di dati

La base di dati è composta da tabelle che contengono tutte le informazioni del sistema. Il database è stato progettato per contenere una grande quantità di dati. Dovrà immagazzinare, infatti, i dati di numerose squadre di atletica, ciascuna delle quali composta mediamente da 20 corridori. Le informazioni sono rappresentate da dati personali, parametri biologici, caratteristiche di ciascun atleta e dati relativi ad ogni gara o sessione di allenamento effettuati. Solamente i dati topografici dei percorsi non sono presenti nel database. Questo è dovuto al fatto che essi sono in numero eccessivamente elevato e di conseguenza non risulta conveniente salvarli all'interno del sistema locale, visto il loro utilizzo poco frequente; è stato deciso di reperire tali informazioni da file esterni nel caso in cui debbano essere analizzate dal programma. Infine, è opportuno precisare che si utilizza una base di dati MySQL [4], in grado di fornire tutte le funzionalità richieste senza alcun costo di licenza. Si accede ai dati contenuti nel database mediante l'utilizzo delle librerie MySQL++ [13].

1.2.2 Il software +Atleta

Il software +Atleta è stato sviluppato usando il linguaggio di programmazione ad oggetti Visual C++ [1] e l'ambiente di sviluppo Microsoft Visual Studio 2005 [6]. L'applicazione implementata utilizza inoltre i componenti ActiveX e la libreria MFC (Microsoft Foundation Class library).

Per comprendere il funzionamento del programma esistente, è necessario esaminarne le caratteristiche:

- **Organizzazione delle informazioni:** i dati sono suddivisi in tre grandi categorie, in base alla funzione che ricoprono all'interno del programma. Esse sono:
  - log: sono i dati provenienti dal pulsometro propriamente detti. Ciascuno di essi fa riferimento ad un'unica sessione di allenamento. Tutti i dettagli originali sono visualizzati, ciascuno con la propria unità di misura.
  - Piani di allenamento: corrispondono agli allenamenti tipo che possono essere organizzati ed elaborati.
  - Programmi di allenamento: sono raggruppamenti di più piani di allenamento, secondo un denominatore comune.
- **Funzioni svolte:** al momento attuale sono disponibili le seguenti funzioni, raggruppate per grandi aree tematiche:
  - sicurezza: la riservatezza dei dati è garantita dalla possibilità di effettuare il login con la propria password. Gli account possono essere creati ed esistono due tipi di utente: *l'allenatore* e *l'atleta*. Mentre il primo ha a disposizione i dati personali ed i log relativi a tutti gli atleti della sua squadra, l'utente atleta può solamente visualizzare i propri. Le informazioni utenti possono essere modificate o cancellate in qualsiasi momento.
  - Calendario: scegliendo il giorno del calendario è possibile associare ad una particolare data più piani di allenamento e/o più programmi di allenamento.

– Log: può essere importato o esportato all'esterno, attraverso l'utilizzo di un file in formato XML. Il log può essere modificato dall'utente o dall'allenatore. È possibile vedere quale piano è associato ad un log, raggruppare più log sotto una matrice comune ed effettuare la divisione di un log in più parti in relazione alla sua durata.

– Confronto di log: è possibile effettuare il confronto di due log ed il programma ne mostra i rispettivi valori, il valore massimo, minimo e medio tra i due.

– Grafici: il software prevede la visualizzazione grafica di alcuni parametri di un log in relazione al tempo ed allo spazio: frequenza cardiaca, altitudine, velocità e consumo energetico.

1.2.3 Il pulsometro

Il pulsometro è lo strumento usato per introdurre i parametri biologici degli atleti all'interno del sistema. Ciascun atleta che coopera allo sviluppo di questo progetto, deve necessariamente allenarsi indossando un pulsometro. Al termine di ciascuna sessione di allenamento, deve trasferire tutti i dati sul proprio PC, in quanto il pulsometro generalmente possiede una memoria piuttosto limitata. Durante la fase iniziale della tesi, sono state effettuati approfonditi studi per stabilire quali informazioni immagazzinare nella base di dati e quali invece scartare. In particolare, sondando il mercato, sono stati scelti tre produttori che offrono prodotti di ottima fattura: *GARMIN* [1], *POLAR* [2] e *SUUNTO* [3].

Le pagine web dei produttori offrono informazioni dettagliate riguardo le caratteristiche dei propri prodotti, per cui è stato possibile confrontarle tra loro. In questa fase dello sviluppo del progetto, sono stati presi in considerazione solamente i modelli che rientrassero nella categoria "corsa".

1.3 Software statistico

Una parte importante del lavoro di tesi ha riguardato la creazione della struttura atta ad eseguire l'analisi statistica dei dati. La base di dati MySQL, infatti, non fornisce strumenti sufficienti per questo scopo. Dalle ricerche effettuate in questo senso, è emerso che la soluzione migliore è quella di non implementare alcuna funzione statistica manualmente, ma utilizzare software apposito già esistente. Questa soluzione è la conseguenza delle seguenti considerazioni: implementare ciascuna singola funzione statistica richiede un grande lavoro in termini di tempo per scriverne il codice e per comprendere a fondo la teoria matematica su cui si basa. Inoltre, si ha un'altissima probabilità di commettere errori nell'algoritmo di calcolo. Utilizzando invece un software apposito sono garantiti l'affidabilità, il livello di precisione richiesti, la velocità di esecuzione e la semplicità.

Sul mercato si trovano numerosi software statistici dalle caratteristiche simili, come *SPSS*, *MINITAB* o *R*. Per svolgere questa parte del lavoro di tesi, è stato scelto di utilizzare R, poichè esso offre alcuni importanti vantaggi: non ha costi di licenza, è un software open-source ed è in continuo sviluppo da parte della nutrita community di utenti. Proprio per quest'ultimo motivo, R è un prodotto sempre più utilizzato da Professori e ricercatori universitari. R offre inoltre gli strumenti per essere utilizzato in remoto da qualsiasi altro software e la sua esauriente documentazione al riguardo ne hanno fatto lo strumento ideale per gli scopi del progetto. In questa sezione verrà descritta l'infrastruttura creata per integrare le funzionalità di R all'interno del software +Atleta. In particolare, si sottolinea che l'obiettivo di questa attività non è stato quello di eseguire complesse analisi statistiche, bensì quello di creare l'infrastruttura affinchè i futuri ricercatori che collaboreranno al progetto possano utilizzarla per sfruttare al meglio le potenzialità offerte da R. La sola analisi statistica implementata è stata la regressione lineare dei parametri biologici degli atleti presenti nel database.

1.3.1 Collegamento ad R

Uno degli scopi del progetto +Atleta è quello di creare un modello di simulazione, per poter calcolare in anticipo le prestazioni di un atleta. Numerosi solo gli input che devono essere inseriti nel simulatore per svolgere la sua funzione; alcuni di essi sono i risultati relativi alle regressioni lineari effettuate usando R [8]. La regressione lineare è uno strumento statistico che consente, date due variabili, di predirne una conoscendo il valore dell'altra.

Le caratteristiche di R sono state dettagliatamente analizzate per poter ottenerne l'integrazione all'interno di +Atleta. Lo strumento utilizzato è denominato **R SERVER**; esso è stato creato da alcuni sviluppatori di R e consente di connettere il software statistico con qualsiasi altra applicazione scritta con i più comuni linguaggi di programmazione.

R SERVER è definito come un "DCOM server che contiene un'interfaccia COM a R". Per comprenderne la definizione è necessario conoscere la nomenclatura di tali acronimi:

COM (Component Object Model) è una piattaforma software introdotta da Microsoft [5] nel 1993. Questa tecnologia, nata per permettere la comunicazione tra processi e la creazione dinamica di oggetti, si adatta ad ogni linguaggio di programmazione che la supporti. I componenti/oggetto COM sono implementati in un linguaggio "neutrale", non conosciuto da chi ne fa uso, e possono essere visti come una scatola chiusa di cui non si conoscono i meccanismi interni. Tali oggetti possono essere inseriti in qualsiasi ambiente ed utilizzati mediante l'interfaccia di cui sono provvisti.

DCOM (Distributed Component Object Model) è un'altra tecnologia sviluppata da Microsoft, per consentire la comunicazione tra componenti software distribuiti su una rete di computer. DCOM estende dunque il concetto COM, aggiungendovi la gestione della comunicazione distribuita tra oggetti.

Come descritto, gli oggetti COM/DCOM definiscono uno standard per l'interoperabilità ed assumono una funzione molto simile a quella di una libreria. Questa tecnica di programmazione, simile al paradigma "ad oggetti", è più correttamente definita "a componenti". Un componente è fondamentalmente una unità base che può incapsulare al suo interno funzioni (*metodi*), dati (*proprietà*) e stati.

In riferimento a quanto detto, è importante conoscere la corretta nomenclatura:

- un componente è detto "COM/DCOM server";
- l'utilizzatore di un componente è detto "COM/DCOM client".

Il package R SERVER contiene un DCOM server utilizzato per connettere un'applicazione client con R. Come è stato accennato in precedenza, il package R SERVER fornisce un'interfaccia COM a R, esattamente nello stesso modo in cui oggetti COM e controlli ActiveX le forniscono alle applicazioni che li supportano. R (D)COM server possiede i meccanismi per connettersi con:

- applicazioni standard (ad esempio Microsoft Excel);
- applicazioni scritte in qualsiasi linguaggio di programmazione, che svolgono la funzione di COM/DCOM client; esse usano il motore computazionale di R e ne ricavano gli output grafici e testuali.

La figura nella pagina seguente mostra le relazioni esistenti tra gli elementi appena descritti [11].

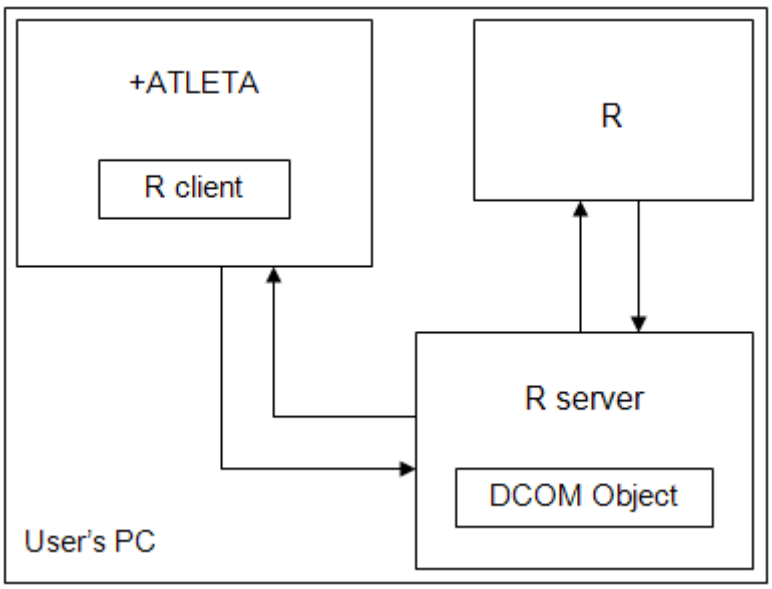


Figura 1.2. Struttura del collegamento ad R

Osservando lo schema precedente si può notare che il cuore della connessione è R server, il quale rappresenta l'anello di congiunzione tra R[1] ed il software +Atleta. +Atleta è l'R client, al quale è consentito l'accesso alle funzionalità di R. R server è in grado di gestire il caso in cui vi siano più applicazioni (R client) che intendano accedere contemporaneamente ad R.

La comunicazione tra client e server avviene mediante lo scambio di particolari oggetti COM/DCOM. Tali oggetti rappresentano il mezzo grazie al quale i dati possono essere scambiati e sono composti essenzialmente da due elementi:

- l'**interfaccia COM,** che contiene i *metodi* e le *proprietà* (variabili) visibili dal client. L'interfaccia rappresenta l'unico punto di accesso all'oggetto COM.

- Il secondo elemento è denominato **Coclass** ed è l'implementazione dell'interfaccia COM. Più Coclass possono implementare la medesima interfaccia.

[1] R deve necessariamente essere installato sulla macchina.

In riferimento a quanto detto, il seguente diagramma di flusso illustra il ciclo di vita di un oggetto COM:

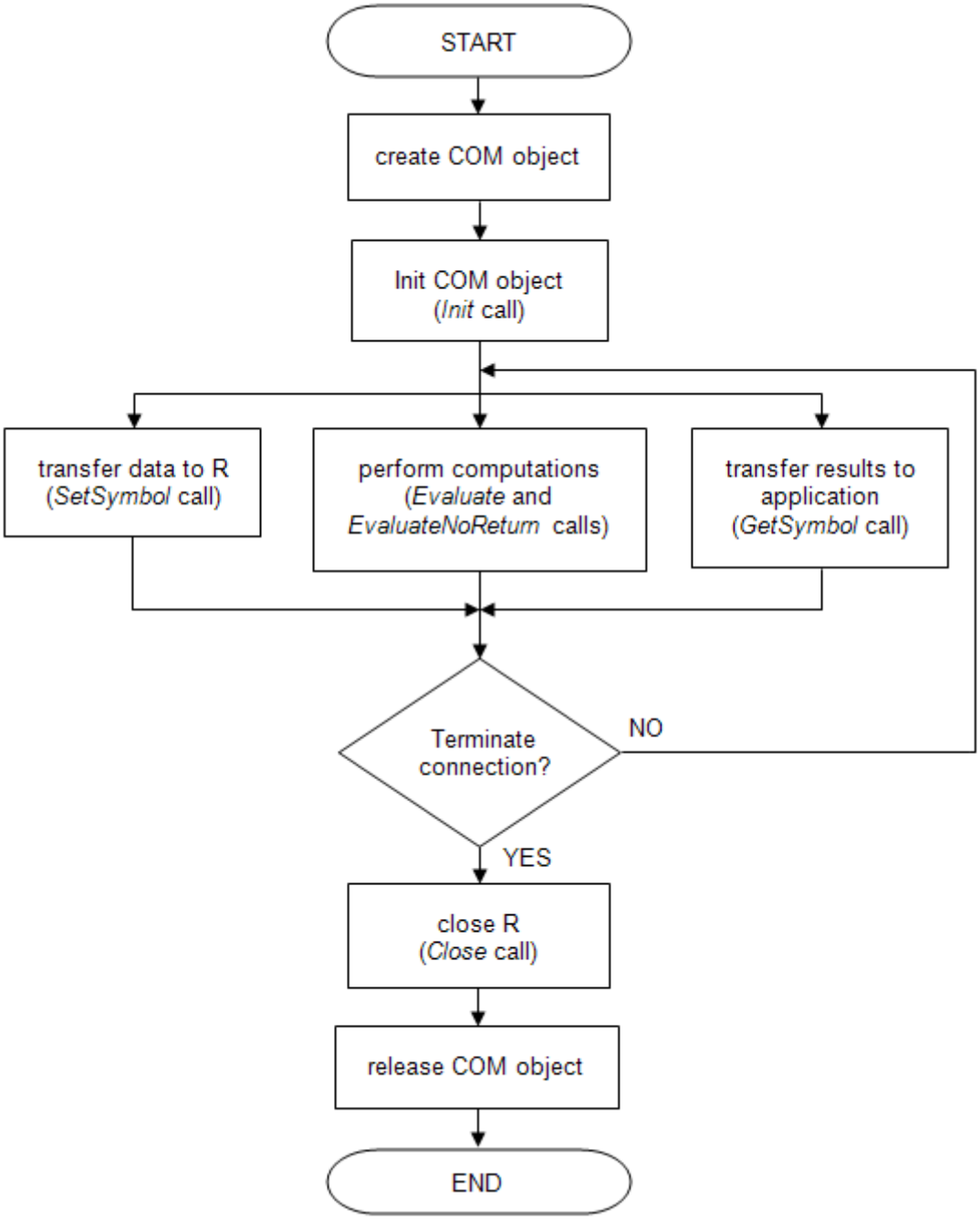


Figura 1.3. Ciclo di vita di un oggetto COM

1.3.2 Regressione lineare usando R

Utilizzando il software statistico R, la regressione lineare tra due variabili può essere effettuata in pochi passaggi [12]:

1. dichiarazione delle variabili: ciascuna variabile deve essere inserita in forma di vettore;

2. comando per la regressione lineare: usando il comando `lm`, viene eseguita la regressione lineare tra due variabili;

3. visualizzazione dei dati: con il comando `plot` si ottiene la rappresentazione Cartesiana (scatterplot) delle variabili;

4. retta di regressione: il comando `abline` visualizza la retta di regressione calcolata;

5. visualizzazione dei risultati: utilizzando `summary` si possono vedere tutte le informazioni relative alla regressione lineare calcolata.

L'esempio seguente chiarisce ulteriormente quanto descritto:

```
x:  1  2  3  4  5  6  7  8  9 10 11 12
y:  23.0 21.5 22.1 21.9 21.8 21.4 22.5 22.3 22.4 22.3 22.2 22.9
> result <-lm (y ~ x)
> plot (x, y, col="4")
> abline (result, col="2")
> summary (result)
```

1.3.3 Motivazioni biomediche della regressione lineare

Il software +Atleta esegue, per il momento, solamente regressioni lineari tra due variabili. Tali variabili sono state selezionate in base alla rilevanza delle informazioni che forniscono sotto il profilo medico/sportivo [14]:

1. FREQUENZA CARDIACA - VELOCITÀ: Il fattore risultante di questa regressione lineare è certamente quello che riveste maggiore importanza. Conoscendo la relazione che intercorre tra frequenza cardiaca e velocità si può stimare il *livello di allenamento atletico* di una persona. Osservando questo parametro si nota se sia necessario o meno variare il carico di lavoro in allenamento per migliorare il rendimento dell'atleta. Per esempio, un'alta velocità di corsa conseguita con una frequenza cardiaca relativamente bassa è indice di un ottimo livello di allenamento.

2. FREQUENZA CARDIACA - ALTITUDINE: il fattore che può essere osservato è l'*adattabilità del fisico all'altitudine*. Ad altitudini elevate (circa 2000 m) svolgere esercizio fisico è più faticoso che ad altitudini inferiori; questo fatto è la conseguenza della minor concentrazione di ossigeno nell'aria, che porta all'innalzamento della frequenza cardiaca e di quella respiratoria.

3. FREQUENZA CARDIACA - DISTANZA: il suo sviluppo indica se l'atleta è allenato sulla lunga distanza. Questo è un fattore di secondaria importanza rispetto a i primi due, ma rappresenta in ogni caso un aspetto da considerare.

4. VELOCITÀ - ALTITUDINE: questo parametro è molto simile a quello descritto nel punto 2. Mantenere un'alta velocità ad alta quota è decisamente più difficile che non ad altitudini inferiori.

5. VELOCITÀ - ENERGIA: assume significato solamente se considerato in associazione con valori della frequenza cardiaca, distanza e pendenza. Tale fattore è molto particolare, in quanto non indica un parametro fisico, bensì uno psicologico. Esso segnala infatti se un atleta si trova a suo agio o meno nella corsa ad una particolare velocità. Alcuni atleti prediligono la corsa a bassa intensità, ma per lunghe distanze; alcuni corridori non si sentono a proprio agio percorrendo tratti in discesa, altri ancora consumano eccessive energie nei tracciati in salita.

6. VELOCITÀ - DISTANZA: questo valore va associato all'analisi tra frequenza cardiaca e distanza [15]. Esso indica il comportamento del fisico sulla lunga distanza,

è utile per capire se un atleta è in grado o meno gestire e razionare le proprie risorse lungo tutto il percorso di gara, in modo tale da mantenere una prestazione costante.

1.4 Algoritmo di analisi dello sforzo fisico

Per poter essere ritenuta efficace, una sessione di allenamento deve provocare un cambiamento all'interno dell'equilibrio fisico di un atleta. Questo particolare fenomeno è detto *omeostasi*. Ogni esercizio fisico è di per sè stancante, ma dopo l'allenamento, durante la fase denominata *di recupero*, il normale stato fisico viene ristabilito. Il fisico si adatta allo sforzo richiesto dall'esercizio svolto in modo tale da poterlo affrontare nuovamente, ma con prestazioni migliori; questo fenomeno è conosciuto con il nome di *supercompensazione*.

Per conoscere il livello di supercompensazione e la giusta frequenza degli allenamenti, è determinante stabilire il livello di sforzo di una sessione di allenamento. Il metodo che è stato utilizzato nella tesi per calcolare lo sforzo è lo stesso suggerito nel manuale di utilizzo del software "POLAR Precision Performance" [2].

Un altro importante fattore da considerare è il tempo di riposo necessario. Esso dipende sia dall'intensità dell'allenamento (frequenza cardiaca) che dalla sua durata. Risulta necessario organizzare la frequenza degli allenamenti, lasciando passare il tempo opportuno tra due allenamenti successivi: non devono essere troppo ravvicinati per evitare il sovrallenamento e non devono essere troppo distanti da non risultare efficaci.

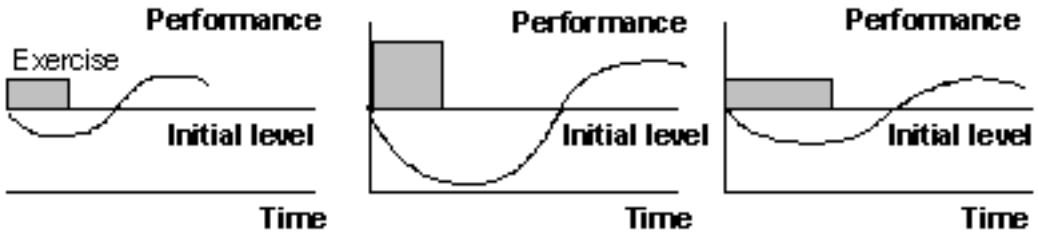


Figura 1.4. Rappresentazione degli effetti di un allenamento sulle prestazioni. Sull'asse delle ascisse è presente la durata e sull'asse delle ordinate l'intensità di un allenamento

Come si evince dallo schema precedente gli effetti immediati di un esercizio sono la diminuzione delle prestazioni. Dopo l'esercizio si entra nella fase di recupero, durante la quale la curva delle prestazioni cresce lentamente fino a raggiungere il livello iniziale. La fase successiva è quella della supercompensazione, nella quale il livello delle prestazioni aumenta fino a superare quello iniziale. Per incrementare visibilmente le prestazioni di un atleta, l'allenamento successivo deve sempre avvenire all'interno fase di supercompensazione.

Il calcolo dello sforzo fisico è stato ideato in modo tale da ricavare un parametro numerico avendo come dati iniziali lo sport praticato, la durata e l'intensità dell'allenamento.

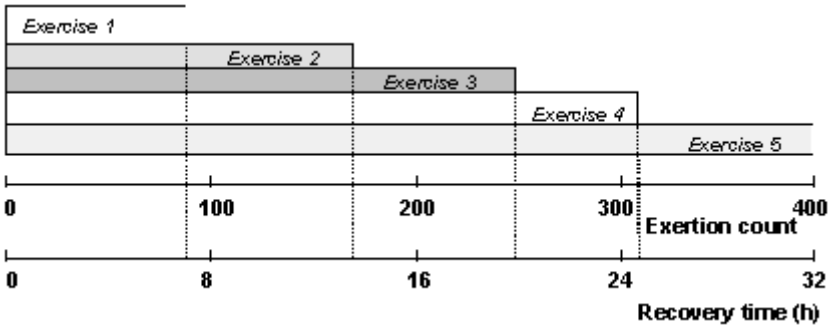


Figura 1.5. Relazione tra sforzo fisico e tempo di recupero

La figura precedente mostra, per esempio, che con un valore di sforzo pari a 300, la relativa fase di recupero deve esse circa un giorno. Terminata questa fase l'atleta è pronto per compiere un nuovo allenamento, poichè il suo fisico si trova nella fase di supercompensazione.

Come anticipato in precedenza, il calcolo numerico dello sforzo fisico è il risultato della combinazione di tre elementi dell'allenamento:

1. durata (tempo, espresso in minuti);
2. intensità (frequenza cardiaca, espressa in battiti al minuto);
3. coefficiente sportivo (coefficiente che dipende dallo sport praticato).

Per ciascun intervallo di frequenza cardiaca, è dato un coefficiente di sforzo per il quale è moltiplicato il tempo trascorso in tale intervallo. Il tutto è poi moltiplicato per il coefficiente relativo allo sport praticato. La formula è la seguente:

$$Sforzo = \sum_{i=0}^{n}[(CS_f\, dell'intervallo\, di\, frequenza) \cdot (tempo\, trascorso)] \cdot (CS_p) \quad (1.1)$$

dove:

- CS_f è il Coefficiente di Sforzo;
- CS_p è il Coefficiente Sportivo;
- *i* è l'indice degli intervalli di frequenza cardiaca;
- *n* è il numero degli intervalli di frequenza cardiaca.

Il coefficiente di sforzo relativo a ciascun intervallo di frequenza è stato ricavato in relazione al seguente grafico:

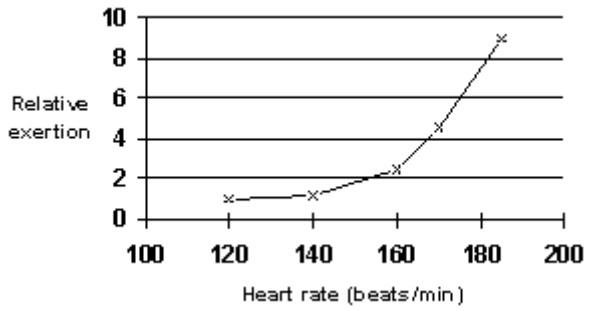


Figura 1.6. Sforzo relativo in funzione della frequenza cardiaca

Il valore dello sforzo fisico è tipicamente compreso tra 50 e 400, mentre il valore del coefficiente sportivo oscilla tra 0.8 e 1.3.

Per quanto concerne l'implementazione, il software utilizza l'algoritmo per visualizzare graficamente il valore dello sforzo fisico di un atleta, consentendo all'utente di

scegliere la finestra temporale mensile o settimanale. Per ciascun allenamento sono mostrati inoltre importanti parametri associati, quali i valori minimo, massimo e medio sia della frequenza cardiaca che della velocità. Il coefficiente sportivo e quello di sforzo relativo a ciascun intervallo di frequenza possono essere modificati a piacere dall'utente; in tal caso il software ricalcolerà nuovamente tutti i parametri.

1.5 Algoritmo di analisi della pendenza del tracciato

Un'altra analisi molto interessante riguarda le prestazioni degli atleti in relazione allo sviluppo altimetrico della corsa. Gli atleti possono avere un comportamento molto differente in termini di velocità o consumo energetico a seconda della pendenza del tracciato. Per esempio, alcuni corridori potrebbero presentare caratteristiche di grande resistenza in salita, ma possedere una tecnica di corsa in discesa non efficace. Analizzando il profilo del percorso in relazione ai parametri biologici degli atleti è possibile evidenziare limiti fisici o atletici, in maniera tale da poter adeguatamente pianificare allenamenti che suppliscano a tali carenze.

L'algoritmo ideato, partendo dai valori puntuali della distanza e della altitudine, rappresentati rispettivamente sull'asse delle ascisse e su quello delle ordinate, crea un profilo altimetrico modificato. L'algoritmo associa tra loro i segmenti che presentano una pendenza simile, presentando un profilo altimetrico meno frastagliato rispetto a quello ottenuto con i dati originari. Tale profilo inoltre può essere studiato con molta più semplicità; esso mette in relazione ciascun tratto del percorso con pendenza costante con parametri quali la frequenza cardiaca, la velocità ed il consumo energetico.

L'algoritmo utilizza l'interpolazione mediante segmenti per calcolare il valore della pendenza. Esistono molteplici metodi per l'interpolazione di punti, ma si è scelto questo in relazione alle seguenti considerazioni:

- è il metodo più semplice;
- non introduce rumore nel calcolo;

- dato che non è possibile conosce l'esatto profilo altimetrico tra due punti, è impossibile stabilire quale sia l'algoritmo migliore;
- è possibile ottenere molti livelli di precisione, modificando alcuni parametri.

L'idea su cui si basa l'algoritmo è quella di scandire completamente il vettore contenente il valore dell'altitudine. Per ciascun elemento si esegue la seguente elaborazione: un punto appartiene ad un certo segmento, se la pendenza del segmento che congiunge il punto stesso ed il punto precedente non eccede una determinata soglia angolare, stabilita in base alla pendenza media del segmento a cui fa riferimento. Nella realtà però, alcuni percorsi presentano dei profili molto particolari: si pensi ad esempio ad un tracciato di montagna dove ci sono numerosi saliscendi. Per questa ragione sono stati presi in esame più punti (e di conseguenza più segmenti) nel calcolo dell'algoritmo, in modo tale da considerare anche la tendenza futura del percorso in questione. In questo modo è possibile non considerare lievi oscillazioni del terreno o valori non corretti dei dati in origine.

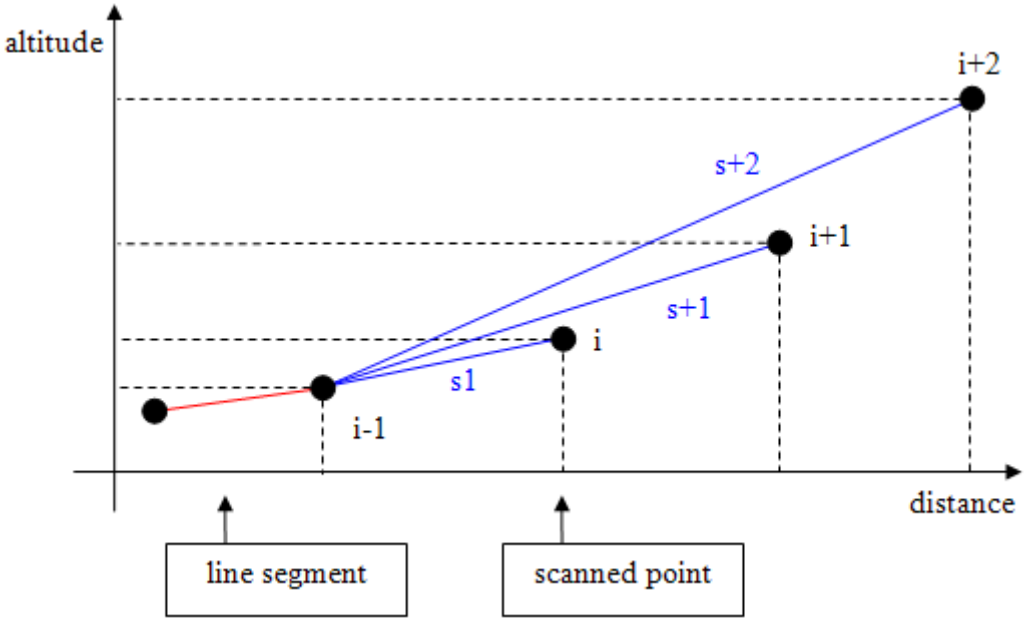


Figura 1.7. Punti coinvolti nell'algoritmo

L'algoritmo di calcolo decide se il punto esaminato ("i") appartiene ad un segmento dopo aver effettuato tre test. Come mostra la figura precedente, il sistema calcola le pendenze dei segmenti "S1", "S+1", ed "S+2" che congiungono rispettivamente i punti "i", "i+1" e "i+2" con il punto precedente a quello considerato ("i-1"). Se almeno una delle tre pendenze così calcolate non eccede la pendenza media del segmento di riferimento, il punto è considerato parte del segmento generale e l'algoritmo procede verso i punti successivi del tracciato. La figura seguente mostra un esempio del profilo che si può ottenere:

Figura 1.8. Profilo mostrato da +Atleta. In blu il tracciato originale, in rosso quello elaborato dell'algoritmo

La classe implementata *gradientView* visualizza sia il profilo altimetrico originale del tracciato che quello ottenuto dall'elaborazione dell'algoritmo. Numerosi parametri statistici associati sono mostrati in forma riassuntiva, suddivisi per range di pendenza: pendenza massima e minima, numero di segmenti appartenenti al range e loro percentuale sul totale, frequenza cardiaca massima e media e per concludere velocità massima e media. Il limite angolare utilizzato può essere modificato dall'utente; in tal caso il software provvede in pochi istanti a rieseguire l'algoritmo ed aggiornare le statistiche. L'interfaccia contiene infine un apposito bottone che consente di vedere le statistiche complete di ciascun segmento individuato dall'algoritmo.

1.6 Algoritmo di analisi delle curve del tracciato

Partendo dalle semplici coordinate topografiche, questa analisi ha l'obbietivo di stabilire il numero di curve di un percorso e la loro direzione. L'importanza di conoscere queste informazioni risiede nel fatto che ciascun atleta ha una la propria tecnica di corsa che dipende enormemente dalla propria gamba preferita. La simmetria del corpo umano non è perfetta, per cui la potenza degli arti inferiori di ciascun individuo non è distribuita equamente. Ciò si traduce in una differenza in termini di velocità e consumo energetico a seconda che l'atleta percorra una curva a destra piuttosto che una a sinistra. Per questo motivo percorrere un tracciato in una direzione o in quella opposta può comportare una differenza di prestazione.

L'algoritmo implementato prende in esame il tracciato di gara o di allenamento, rappresentandolo ed esaminandolo come una sequenza di segmenti. I dati a disposizione sono le coordinate topografiche rilevate utilizzando un apparecchio GPS (Global Position System) e sono rappresentati mediante un grafico Cartesiano. Le coordinate Cartesiane vengono trasformate in coordinate Polari per una più semplice analisi: in questo modo non si hanno a disposizione punti, ma segmenti. L'elaborazione successiva coinvolge una coppia di segmenti adiacenti alla volta: a seconda dell'ampiezza dell'angolo tra essi compreso, si presenta uno dei seguenti casi:

- se il valore angolare è molto elevato e supera la soglia prestabilita (angolo limite), non c'è alcuna curva;
- se l'angolo ha un'ampiezza che non supera l'angolo limite si presentano due alternative:
  - si è in presenza di una curva se la curva precedente è più distante di una certa soglia (distanza limite) oppure se la curva precedente è nell'altra direzione;
  - non c'è una nuova curva, poichè quella in esame fa parte di una curva più grande, delimitata da più di due segmenti consecutivi.

L'algoritmo compie una roto-traslazione degli assi cartesiani per ogni coppia di segmenti adiacenti, in modo tale da sovrapporre l'asse delle ascisse con il primo dei due

segmenti considerati. Questa operazione è essenziale per stabilire, in base alla posizione del secondo segmento, la direzione della curva in esame. Il seguente schema aiuta a chiarire il concetto esposto:

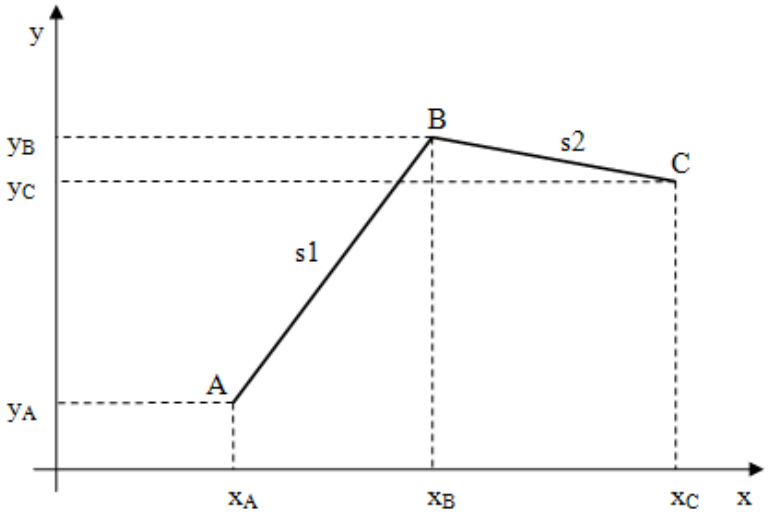


Figura 1.9. Configurazione standard degli assi

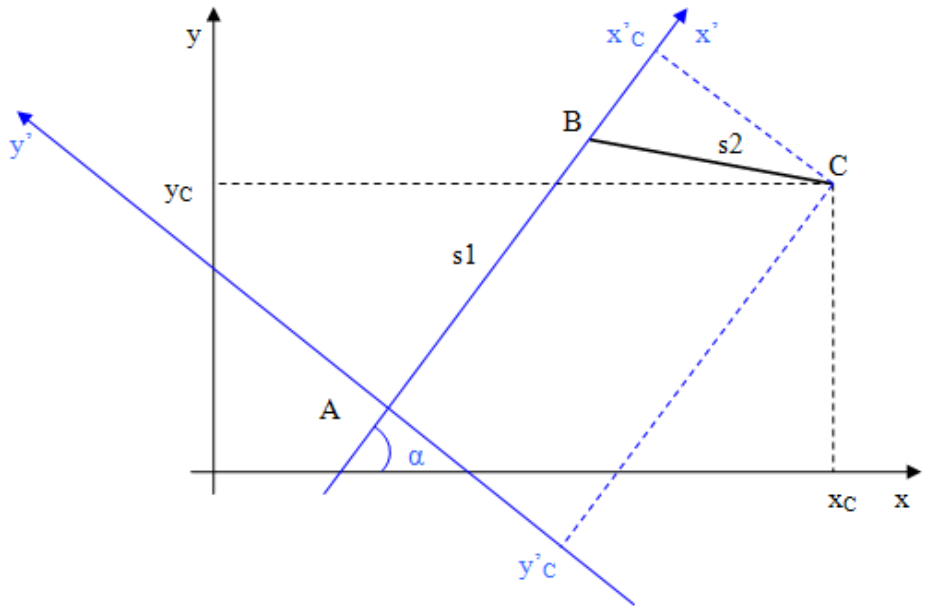


Figura 1.10. Roto-traslazione degli assi

Riassumendo quanto detto finora, l'algoritmo riconosce in quale scenario si trova la curva analizzata e ne provvede ad immagazzinare i parametri associati, quali la frequenza cardiaca, la velocità, la pendenza ed il consumo energetico. Nel caso in cui una curva sia composta da più di due segmenti consecutivi, i predetti parametri sono calcolati come valore medio tra tutti quelli coinvolti.

Per quanto concerne l'implementazione, la classe *bendView* consente di visualizzare la planimetria del tracciato e fornisce numerose statistiche associate, quali l'ampiezza massima, minima e media dell'angolo della curva, la percentuale di curve a destra ed a sinistra sul numero totale di curve, la frequenza cardiaca media, la velocità media e la pendenza media. Esistono poi due tipi di statistiche riassuntive: la prima suddivide le informazioni citate in intervalli di ampiezza di angolo della curva, mentre la seconda raggruppa i valori in base a range di pendenza. Inoltre, l'interfaccia consente all'utente di modificare i due importanti parametri coinvolti nell'algoritmo: l'angolo limite e la distanza limite. Se tali parametri vengono modificati, il software riesegue l'algoritmo ed aggiorna i valori delle statistiche. L'utente ha la possibilità di consultare i dati esaustivi relativi a ciascuna curva cliccando sull'apposito bottone.

1.7 Conclusioni

Al termine del lavoro effettuato si possono trarre le conclusioni su ciò che è stato conseguito. L'attività di tesi ha portato alla definizione di nuove ed importanti funzionalità del software +Atleta. In particolare è stata creata la struttura atta a compiere la regressione lineare dei dati presenti nel database del sistema. Attraverso un'opportuna interfaccia, è possibile scegliere su quali dati effettuare la regressione lineare ed automaticamente il sistema provvede a connettersi ad R, inviare le informazioni necessarie e ricevere il risultato delle elaborazioni in pochi istanti. Queste ultime sono mostrate all'utente sotto forma grafica e corredate dai più importanti dati statistici associati. La regressione lineare non si effettua su tutti i dati biologici che si hanno a disposizione, ma solamente su quelli che sono stati selezionati in base alla rilevanza che assumono dal punto di vista medico-sportivo.

L'obiettivo di questo lavoro non è stato quello di effettuare profonde ed elaborate analisi statistiche dei dati, bensì quello di impostare una infrastruttura semplice ed efficace affinché tali analisi possano aver luogo. È stata in questo modo ideata la base sulla quale si fonda il lavoro di altri ricercatori che collaboreranno al progetto, i quali disporranno di uno strumento funzionante e potranno sfruttare la dettagliata documentazione al riguardo per utilizzare al meglio le grandi potenzialità che offre il software statistico R.

Inoltre, gran parte del lavoro di tesi è stato quello di ideare e realizzare tre algoritmi di analisi di dati relativamente allo sforzo fisico dell'atleta, al profilo altimetrico del percorso di gara ed alla planimetria della corsa. Tali analisi si occupano di particolari e delicati aspetti della preparazione atletica ed hanno lo scopo di visualizzarne approfondite e dettagliate statistiche; rivestono inoltre un ulteriore funzione: quella di calcolare determinati parametri che potranno essere utilizzati come input per il DSS che verrà implementato nei prossimi anni, utile per prevedere le prestazioni di un atleta in una competizione non ancora avvenuta. Infine, per facilitarne la diffusione e l'utilizzo, seppur per il momento solamente in ambito accademico, è stato realizzato un comodo installatore per i sistemi operativi Microsoft. Esso installa in pochi passaggi il software +Atleta, il database MySQL e tutti i componenti aggiuntivi necessari per il coretto funzionamento.

Per quanto riguarda invece la realizzazione dei componenti software, si è cercato di favorire l'aspetto architetturale della progettazione, cercando di suddividere il più possibile ciascun ambito e di utilizzare un approccio modulare. Grazie ad esso è stato possibile fornire un certo grado di estensibilità, mediante la quale sarà possibile aggiungere nuove funzionalità al progetto, senza doverne necessariamente modificare l'intera architettura. Uno dei principi che ha guidato il lavoro di tesi è stato cercare di rendere le diverse componenti il più possibile compatibili con il resto del sistema, anche sotto il profilo grafico, in maniera tale da rispettare e seguire le linee guida tracciate da chi vi ha lavorato precedentemente. Un ulteriore scelta progettuale è stata quella di continuare ad usare standard e raccomandazioni ampiamente accettate a livello internazionale per la realizzazione di ogni componente: ne sono esempi la creazione del collegamento con il software statistico

mediante R-server, strumento in continuo aggiornamento e sviluppo che garantisce grande longevità al progetto oppure l'utilizzo della tecnologia ActiveX per la visualizzazione di tutti i grafici. Da sottolineare infine, che l'attività di creazione delle interfacce utente è stata eseguita ponendo particolare attenzione alla semplicità, intuitività ed immediatezza nel loro utilizzo; ciascuna interfaccia è stata concepita in modo tale da possedere due livelli di precisione: un livello principale nel quale sono contenute le informazioni che rivestono un ruolo fondamentale ed un riassunto dei dati suddivisi per categoria, ed un livello secondario più approfondito e completo, riservato agli utenti con necessità di vedere informazioni dettagliate su un determinato tema.

Come già evidenziato più volte all'interno della tesi, il lavoro svolto all'interno del progetto +Atleta ha riguardato la terminazione dell'intera infrastruttura del sistema. Tuttora il progetto si trova in fase di pieno sviluppo e molti sono i collaboratori che ne prendono parte, ognuno di essi occupandosi di un aspetto specifico. Le tematiche in questione sono numerose e affrontano sia lo sviluppo di nuove funzionalità che il miglioramento di quelle esistenti; ad esempio vi è lo scambio di dati tra i pulsometri professionali ed il sistema che non è ancora automatico e semplice come dovrebbe essere quello di un software che vuole incontrare un numero elevato di utenza. Inoltre, il lavoro da me svolto si occupa unicamente del funzionamento su una singola macchina. Alcuni ricercatori stanno realizzando un sistema distribuito, grazie al quale si potrà accedere alle funzionalità del software anche attraverso il web; in questo caso l'architettura tradizionale del sistema verrà rivoluzionata per assumere la conformazione tipica del modello *client-server*. In altre parole, quello che si vuole ottenere è una scissione netta tra il software, che rappresenta il motore dell'applicazione, ed il database che ne contiene le informazioni.

Il progetto +Atleta prevede due tipi di prospettive future: la prima riguarda il breve periodo mentre la seconda è a lungo termine. Nel prossimo futuro, nell'arco di duo o tre anni, è prevista l'ultimazione del progetto generale con la messa a punto sia del simulatore che del DSS. Entro questo periodo ci si propone inoltre di estendere le funzionalità del software, riservate per il momento solo alla corsa, a molte altre discipline dell'atletica. A lungo periodo invece, una volta che il sistema risulti perfettamente funzionante sugli

atleti, ne è prevista l'applicazione in campo medico. L'idea nasce dal fatto che, una volta conosciuti i dati relativi al comportamento di un fisico sano, eventuali parametri che si discostino eccessivamente da essi potrebbero essere sintomo di disfunzioni o patologie; in questo caso +Atleta diverrebbe un utilissimo strumento di prevenzione.

Summary

The goal of this thesis is to describe my work of cooperation done at the UPC (Universitat Politècnica de Catalunya) and to intensify the knowledge about the related theoretical aspects. As my work is concerned, it can be described as a collaboration in the *+Atleta* project. It begun in 2005 and nowadays it is still in phase of development. The goal of this project is the creation of a DSS (Decision Support System) for sport activities, that is a software for professional use whose aim is to help an athlete to improve his/her performances. By starting from deep analysis of body parameters, the software will be able to simulate the future performances of the athlete. This thesis work is focused on the improvement of the existing project, adding on new functionalities and capabilities. In this phase of project development, the attention is focused on creating the main infrastructure that could allow performance simulation in the future. Numerous data have to be taken into consideration, some of them are: body parameters, training or race courses and whether conditions. In particular, data which have been studied and implemented are data analysis about body exertion, altimetric track profile and topographic track profile. This analysis has involved the creation of many statistical views, grouped into thematic areas, and statistical analysis of some important factors using linear regression. The work had started from the knowledge of the existing project and, through the technical analysis of the infrastructure creation, it finished with the implementation of new software functionalities. In the present document, objectives, planning methods and development phases which have been developed during the thesis period are described in detail. Finally, a final evaluation about the work done, as well as the conclusions and the considerations about the future of the project, are present in this thesis.

Acknowledgements

This research activity would not have been possible without the contributions of the Prof. Pau Fonseca i Casas and the Prof. Elena Baralis. I am grateful for his and her time, suggestions and detailed comments. On my personal side, I would like to acknowledge my family, who has always supported me during these years at the University and has believed in me.

Contents

Chapter 1

Introduction

At the present time, the competitiveness at professional level in the sport world is so high that any way or instrument that could help to improve athlete's performances has been pursuing. In the last few years, the use of technology has become more and more frequent, since people understood that its use in sport disciplines gave an improvement of precedent results. Nowadays, at professional level, a little margin of improvement could even mean the achieving of a new world record or, more simply, a new victory.

Human nature is very competitive and every person has the tendency to improve and surpass himself and his limits, day by day. In order to achieve this important objective, it is necessary to always work at full capacity. For this reason, all parameters that could improve the performances must be controlled. It exists nowadays a large number of worldwide companies, indeed, that invest for years in this kind of projects. These projects could involve a broad spectrum of activities: some producers make professional instruments capable of store body parameters of athletes, others offer analysis services of these data as decision support system about the physical state of a person, others make special sportswear depending on the sporting discipline. Furthermore, numerous new specialized sports centers have been created, generally from sports clubs of great importance. There, high technology and specialized staff are used to achieve the improvement of athletes' performances.

Into this complex scenario, the project called "+Atleta" was born at the UPC (Universitat Politècnica de Catalunya) in Barcelona. This project, managed by the Professor Pau Fonseca i Casas, is put in the area of interest of the body data analysis. It was devised after a long and deep research about similar products present in the market. By analyzing all the characteristics of +Atleta strong and weak points, its limitations, many possibilities of future improvements have been highlighted. Leader companies in this market's sector have been taken as a model; in particular, three worldwide companies: POLAR, GARMIN and SUUNTO. They produce professional training computers and furnish to their customers their own software. It provides to visualize and manage data retrieved during any race or training session. Biological data are not subjected to deep analysis, but in the majority of cases they are displayed as graph or table view. This means that these software do not provide more information than the ones that training computers provide in real time during a training session. Data are just visualized in a more comprehensible form. Moreover, the customer must utilize the furnished software, because each company has its own format data. This last point represents a considerable disadvantage, because it is not possible to analyze data from products of different brands. As consequence of these considerations, what has been occurred to mind was the idea of creating a new product who can compensate lacks of existing ones. It overcomes their limitations and represents a new alternative, especially for professional use. +Atleta project is an instrument who can offer new capabilities in biological data analysis. It was born in September 2005 and it is still now in phase of development. This is a long-term project, its aim is to create a DSS (Decision Support System), a very complex software capable of doing a constant and detailed monitoring of the sporting performance of numerous athletes. Furthermore, it is able to perform deep data analysis to reach the athletes' increasing performances. Through the analysis of a great quantity of data, the DSS is a real simulation system and its aim is to predict in advance, with particular atmospheric and environmental conditions, future athlete's results on a certain sport discipline, on a given track route.

The product's lacks present on the market are transformed into the strong point of this project. By using their training devices, +Atleta software is planned to be a standard

instrument able to obtain data from any device, independently from its brand or model. Retrieved data are translated and mapped on a XML format file (see paragraph 2.4.3) and subsequently stored into a MySQL database. On the one hand, data are shown to the user as graph or table view, in order to highlight the most significant ones. On the other hand, they are subjected to more complex elaboration and processes which calculate numerous biological parameters. These estimated parameters represent the DSS' input variables and they assume an important role into the athlete's performance simulation.

The goal of the present thesis is to describe my cooperation work and my assumed role into the +Atleta project development. A large number of complex work phases are needed to complete +Atleta project. They are described in the paragraph 2.1 (Project planning) and are planned in such a manner that can be developed by several people at the same time. A preparatory phase of the work was focused on the study of the existing project's architecture, functioning and on the project development. The amount of work that has to be done is very high and is so complex that students and researchers with others university careers are involved into the project. My work's contribution is located in the phase of completion of the existing system's infrastructure, which is described in detail in chapter 2. Two main aspects have been taken into consideration: the first is the creation of the statistical data analysis structure, by the implementation of a connection with the R software; the previous step was the study of R's capabilities, then the attention has been paid on the implementation of the linear regression, a particular statistical analysis which provides interesting information about the physical state of an athlete. Nevertheless, the main aim of this work has been the detailed structure documentation, the description of every connectivity's mechanism between R and +Atleta. In this way, future researchers (specialized into sports medicine) will utilize it to do more complex, efficient and useful data analysis. Chapter 3 explains what previously has been said. The second aspect taken into consideration is the creation of three analysis algorithms related to athlete's exertion, track's gradient and bends of the training way respectively. Their goals are to show statistics and to count parameters which can be used as input for the simulator engine. Their theoretical aspects and functioning are described in detail in chapter 4. Chapter 5 of the

thesis explains algorithms' implementation on Visual Studio 2005 framework. Moreover, a special user-friendly interface which permits to use in a simple way the new +Atleta's functionalities has been implemented. Moreover, all characteristics, features, planning decisions, classes architecture, use case diagrams and sequence diagrams are present, too. Finally, chapter 6 contains the conclusions about the work that has been done, it describes the current project's situation and explains its future development.

Chapter 2

Existing project

2.1 Project planning

+Atleta is certainly a very ambitious project, that requires a big work in terms of time and human resources. For this reason it has been planned and organized in such a manner to be developed by numerous students, everyone with a different assigned work, depending on the type and the level of their previous university careers. Due to its complexity, the project development is organized as a multi-year activity, and it is possible to identify three basic phases. Each one is divided into several sub-activities:

- **infrastructure creation:** it consists in software planning, requirement decision, setting up its characteristics and its functional working, planning which functions have to be implemented and finally deciding which kind of data utilize. This represents the base for the following development phases. For this reason, this infrastructure creation is divided into the following activities:
  - determination of software requirements and its functions;
  - determination of data type to be researched;
  - determination of data format;
  - determination of database structure and how to manage it;
  - software implementation;

  - parser implementation, to import and normalize data from external devices that will be stored into the database;
  - data visualization in a useful and comprehensible shape;
  - data management;
  - creation of statistical data analysis structure;
  - creation of web access structure.

- **Data retrieval:** it represents a collaboration between project developers and different existing athletics teams. This phase is necessary to retrieve great quantities of valid data. Its start is estimated on January 2008 and its duration is exactly one year. The starting point is not a parameter as restrictive as the duration. The duration is the most important factor of this development part of +Atleta project, because the aim is to obtain training data of all seasons. This is due to the fact that it's important and useful compare the athlete's performance related to the same training session, but done in different seasons to study if and how climatic conditions affect it. Data retrieval is divided into sub-activities:

  - detection of athletes teams which cooperate with the project in question;
  - detection of retrieval data procedure;
  - retrieval data phase;
  - validation data procedure;
  - possible database modification.

- **Data analysis:** this final phase consists in finding the existing relationship, considered in forms of mathematical and statistical functions, between the parameters studied and retrieved in the previous phases. This work has the goal of extrapolating information from founded relations, and helping trainers to understand how athletes performances can be improved. It involves a deep initial statistics study joined with an excellent body parameters knowledge. The whole project terminates with the DSS (Decision Support System) creation. It is a very complex work because it involves the use of a simulation model, to predict the future athlete's performances.

A temporary simulation model implementation will be performed, then the establishment of the used variable, hypothesis and development paradigms. Models will be created and implemented. The final simulation model will be ready after a deep test session. Tests are divided into three parts: *validation* is used to establish if the used simulation models are the correct ones. *Verification* is used to check if was performed the right model implementation. The final step is *accreditation*, i.e. the certification of a person, a body or an institution as having the capacity to fulfill this particular function. A further difficulty is to choose which information have to be shown to the user and in which way.

Data analysis phase is composed by:

- determination of work hypothesis;
- deep statistics data study;
- body parameters study;
- determination of relationship between different parameters;
- initial simulation model construction:
  - determination of Variables;
  - determination of Hypothesis;
  - determination of Paradigms.
- Models implementation;
- tests:
  - validation;
  - verification;
  - accreditation.

At the moment, considering this work's contribution, +Atleta project is at the end of the first phase, *infrastructure creation*. In the next page it is possible to see the general Gantt diagram of the project.

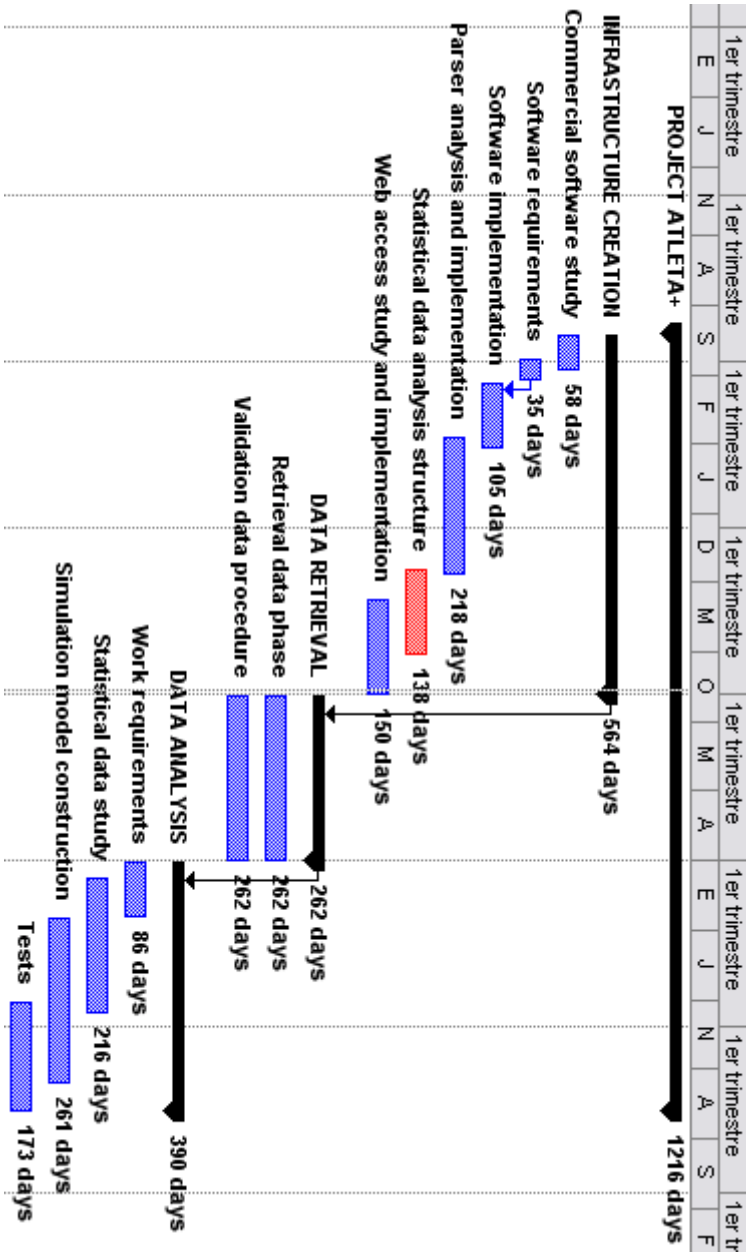


Figure 2.1. General Gantt diagram

2.2 Current situation

The initial part of the present thesis is focused on the study and the analysis of the existing system. Making reference to the planning phases of the project described in the previous paragraph, it is necessary to examine the present situation in order to proceed to the accurate description of the thesis work.

Currently, +Atleta project is close to the end of the first planned phase (see project planning paragraph). It means that this work and the one of others students involved in the project development, is focused on the creation of the whole program infrastructure. To carry out the infrastructure is a crucial step for software development. It is considered one of most important milestones, because all the future developments have as base the work done in this primary phase.

At the moment, the mentioned DSS takes only one sport into account: one is speaking about *running*, which behaves to the category of *athletics*. In particular, software is planned to manage running in all its different forms:

- **track events**, running events conducted on a 400 m track:
  - sprints: events up to and including 400 m. Common events are 60 m (indoors only), 100m, 200m and 400m.
  - Middle distance: events from 800m to 3000 m, 800m, 1500m, mile and 3000m. Belongs to this category the steeplechase - a race (usually 3000 m) in which runners must negotiate barriers and water jumps.
  - Long distance: runs over 5000 m. Common events are 5000 m and 10000 m. Less common are 1, 6, 12, 24 hour races.
  - Hurdling: 110 m high hurdles (100 m for women) and 400 m intermediate hurdles (300 m in some high schools).
  - Relays: 4 x 100m relay, 4 x 400 m relay, 4 x 200 m relay, 4 x 800 m relay, etc. Some events, such as medley relays, are rarely run except at large relay carnivals. Typical medley relays include the distance medley relay (DMR) and

the sprint medley relay (SMR). A distance medley relay consists of a 1200 m leg, a 400 m leg, an 800 m leg, and finishes with a 1600 m leg. A sprint medley relay consists of a 400 m leg, 2 200 m legs, and then an 800 m leg.

- **Road running:** conducted on open roads, but often finishing on the track. Common events are over 5km, 10km, half-marathon and marathon, and less commonly over 15km, 20km, 10 miles, and 20 miles. The marathon is the only common road-racing distance run in major international athletics championships such as the Olympics.

- **Race walking:** usually conducted on open roads. Common events are 10km, 20 km and 50 km.

2.3 Project guidelines

+Atleta project is planned to achieve a large number of consumers. In order to obtain this goal, it must have the following features:

1. One of the most important characteristic of the software is the simplicity of user's use, in the sense that the user can immediately understand how the application works and most of all he can easily transfer data from the device to the database. For this reason, software is developed to be the most possible user-friendly, with an extremely intuitive interface. Furthermore, it must be the more automatic as possible to help user in the best manner.

2. Another important feature consists in reaching the compatibility and standardization with each device and the possibility of doing the same (or almost the same) data analysis of a training session, independently of the device brand. This is due to the fact that not all users can afford to buy the most expensive device or to buy the whole training set. This is a focal point which is difficult to reach for two reasons:

    - each model of training device returns different parameters; for example high level heart monitors have more data than low level ones or some product does

not give longitude and latitude coordinates;

- the data format of different brands can be different.

3. The project is planned to be standard and does not use owner solutions as much as possible. For this reason, it uses XML format file to structure body and log information, that is a standard and a free license format file. Furthermore, it uses a MySQL database, whose license is free.

4. The program must show graphic and processed information about runner performances and the user can choose rapidly which data will be displayed or not. Furthermore these data must be compared with previous performances or with other runner's performances.

5. System could in the future be utilized for lots of sports and different activities. At the moment, our concentration is focalized only on running subject. Once running project will be terminated, the project will be developed toward different sports.

2.4 Project description

This system is complex and is basically composed by three different parts:

- **Database:** it stores data of all the athletes and trainers; most quantity of data are originated by running computers and only a little quantity are inserted manually. Other stored data are generated by software processing.

- **Software +Atleta:** it permits to the user to have a complete view of its training data; they involve training plans, graphic and table views of numerous biological parameters. These data can be analyzed and processed by the program. It manages database connection and data storage.

- **Running computer/external device:** it provides the major part of input data. In particular, it furnishes body parameters about each race or training session.

The following figure shows the system's elements and the exchanged data flow:

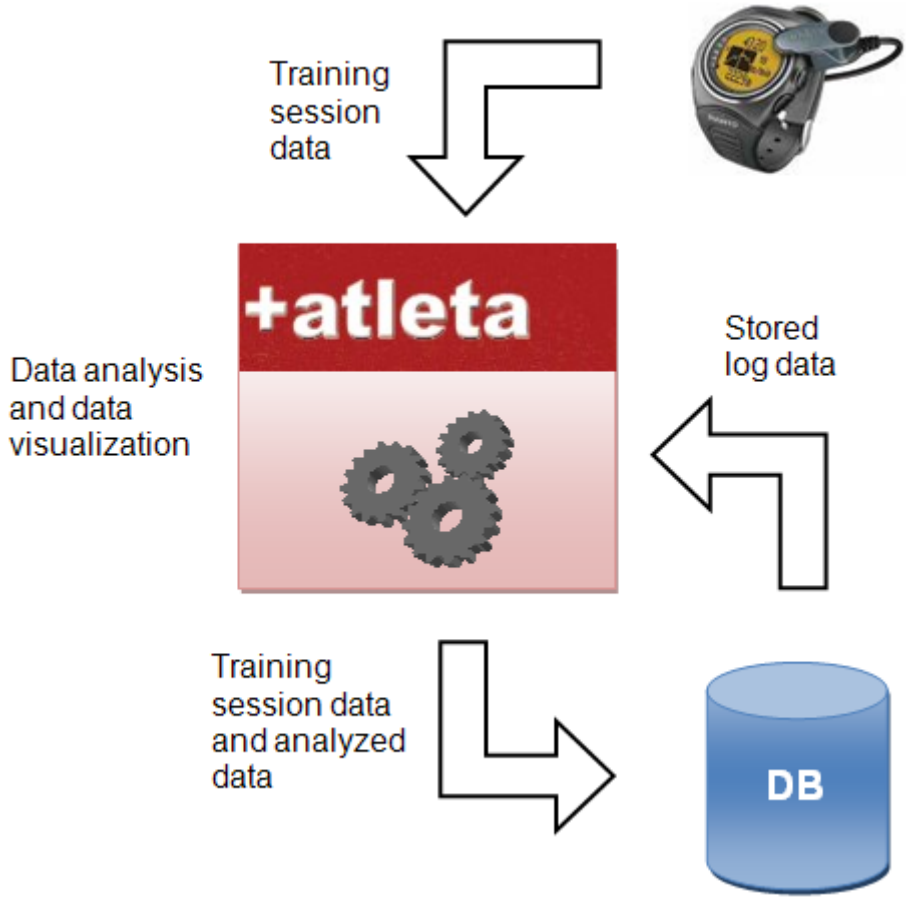
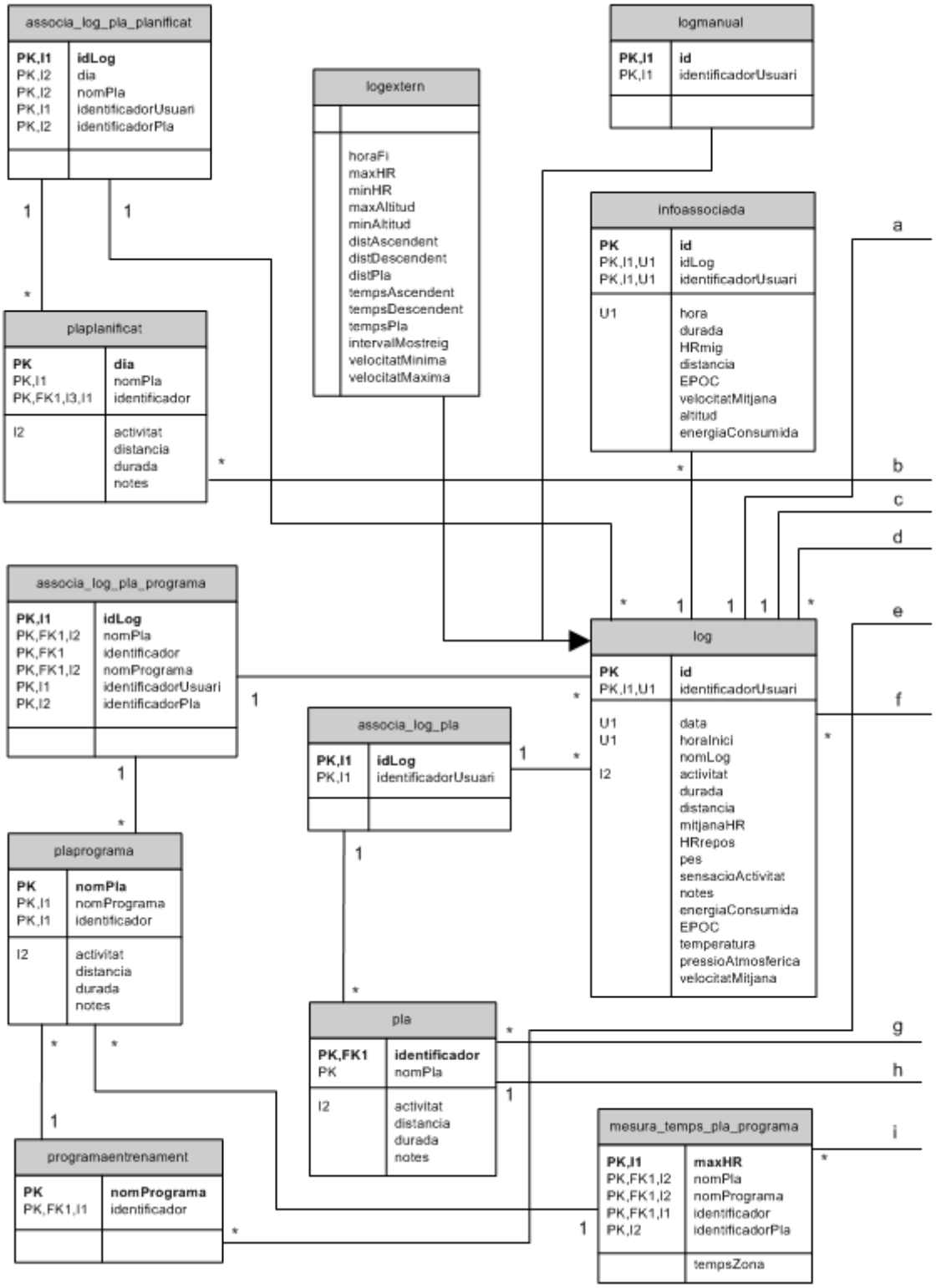


Figure 2.2. System's elements

2.4.1 Database

Existing database is composed by tables which contain the whole training system information. It is planned to store a great quantity of data. They are related to numerous athletics teams, each one is composed by 20 athletes. Information could be personal data, biological parameters and characteristics of every athlete and body data about all training session or race done. Only topographic tracks information are not stored in the DB. This is due to the fact that they are so many that it is not convenient to save them. In agreement with the project manager, it is been decided to retrieve track information from external file when it is needed to analyze them and not to store them into the local system. Finally, the database is a MySQL DB [4], which provides all functionalities needed without any license costs. It is accessed by using the MySQL++ library [13], described in the next paragraph.

More in detail, the database structure is described by the following figure:


associa_log_pla_planificat
PK,I1 idLog
PK,I2 dia
PK,I2 nomPla
PK,I1 identificadorUsuari
PK,I2 identificadorPla
logmanual
PK,I1 id
PK,I1 identificadorUsuari
logextern
horaFi
maxHR
minHR
maxAltitud
minAltitud
distAscendent
distDescendent
distPla
tempsAscendent
tempsDescendent
tempsPla
intervalMostreig
velocitatMinima
velocitatMaxima
infoassociada
PK id
PK,I1,U1 idLog
PK,I1,U1 identificadorUsuari
U1 hora
durada
HRmig
distancia
EPOC
velocitatMitjana
altitud
energiaConsumida
plaplanificat
PK dia
PK,I1 nomPla
PK,FK1,I3,I1 identificador
I2 activitat
distancia
durada
notes
associa_log_pla_programa
PK,I1,PK,FK1,I2,PK,FK1,PK,FK1,I2,PK,I1,PK,I2 idLog
nomPla
identificador
nomPrograma
identificadorUsuari
identificadorPla
log
PK id
PK,I1,U1 identificadorUsuari
U1 data
U1 horaInici
nomLog
I2 activitat
durada
distancia
mitjanaHR
HRrepos
pes
sensacioActivitat
notes
energiaConsumida
EPOC
temperatura
pressioAtmosferica
velocitatMitjana
associa_log_pla
PK,I1 idLog
identificadorUsuari
plaprograma
PK nomPla
PK,I1 nomPrograma
PK,I1 identificador
I2 activitat
distancia
durada
notes
pla
PK,FK1 identificador
PK nomPla
I2 activitat
distancia
durada
notes
mesura_temps_pla_programa
PK,I1,PK,FK1,I2,PK,FK1,I2,PK,FK1,I1,PK,I2 maxHR
nomPla
nomPrograma
identificador
identificadorPla
tempsZona
programaentrenament
PK nomPrograma
PK,FK1,I1 identificador
a
b
c
d
e
f
g
h
i

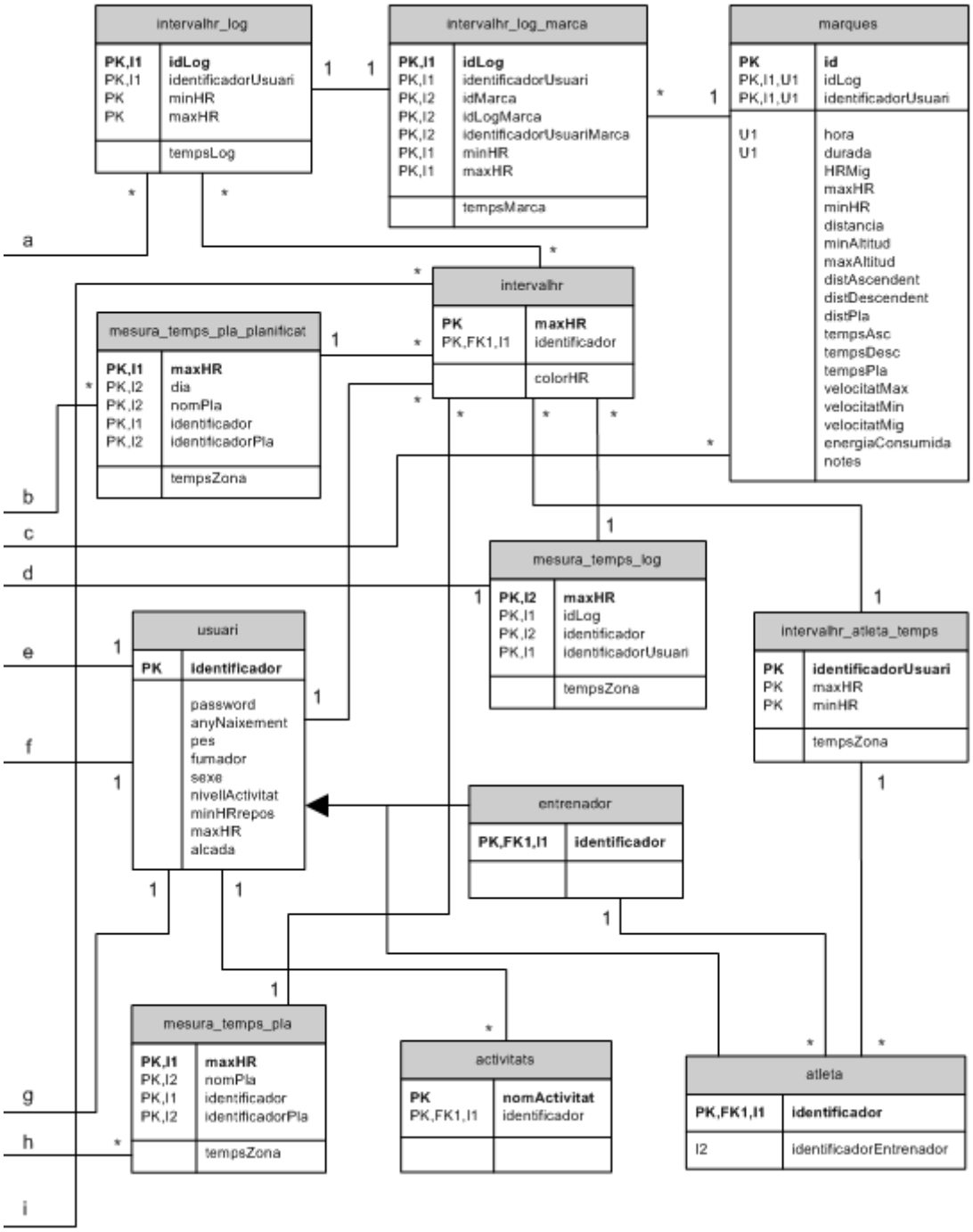


Figure 2.3. Database schema

MySQL++ library

MySQL++ is a powerful C++ wrapper for MySQL's C API. It is built around STL (Standard Template Library) principles. MySQL++ helps the programmer to manage C data structures, to generate easily repetitive SQL statements, and to manual creation of C++ data structures to mirror the database schema.

MySQL++ [5] has developed into a very complex and powerful library, with different ways to perform a task. The purpose of this section is to provide an overview of the most important used components of the library.

The process for using MySQL++ is similar to that of most other database access APIs:

1. to open the connection;
2. to form and execute the query;
3. to iterate through the result set.

Connection and query execution

Any connection to the MySQL server is managed at least by a Connection Object. The most important function of the Connection is to create Query Objects for the user, which are used to execute queries. The library also allows to execute queries directly through the Connection Object, although the more powerful Query Object is strongly recommended to execute queries.

To set up the Query Object to perform query executions there are three different ways:

1. standard **Query Object** is the recommended way of building and executing queries. It is subclassed from `std::stringstream`, which means that it can be used like any other C++ stream to form a query. The library includes also stream manipulators, which generate syntactically-correct SQL. This is the utilized method in +Atleta system.

2. Another useful instrument is the use of a **Template Query**. It works like the C `printf()` function. The user sets up a fixed query string with tags inside, which indicate where to insert the variable parts. This can be very useful in the case of multiple queries that are structurally similar, because it is only necessary to set up one template query, and use that in the various locations of the program.

3. A third method for building queries is to use **Specialized SQL Structures** (SSQLS). This feature presents the results as a C++ data structure, instead of accessing the data through MySQL++ intermediary classes. It also reduces the amount of embedded SQL code that a program needs. Unfortunately, a Visual Studio 2005 bug does not allow users to utilize this method into the framework.

The field data in a result set are stored in a special `std::string`-like class called ColData. This class has got conversion operators that let the programmer automatically convert these objects to any of the basic C data types. Additionally, MySQL++ [4] defines classes like *DateTime*, which can be initialized from a MySQL DATETIME string. These automatic conversions are protected against bad conversions, and can either set a warning flag or throw an exception.

As for the result sets as a whole, MySQL++ offers different ways of representing them:

- **Queries that do not return data.** Not all SQL queries return data. An example is CREATE TABLE. For these types of queries, there is a special result type (ResNSel) that simply reports the state resulting from the query: whether the query was successful, how many rows it impacted (if any), etc.

- **Queries that return data: dynamic method.** The easiest way to retrieve data from MySQL is using a Result object, which includes one or more Row objects. Because these classes are `std::vector`-like containers, it is easy and powerful to manage the result set as a two-dimensional array. For example, to obtain the fifth item on the second row, what has to be typed is: `result.at(1).at(4)`. It

also allowed the access to row elements by field name, like the following example: `result.at(2)[``altitude'']`. An alternate way of accessing to the query results is through a ResUse object. This class acts more like a Standard Template Library input iterator than a container: programmers can analyze the retrieved result set one item at a time, always going forward. This system has the disadvantage that it is not possible to know how many results are in the set until the end is reached. Finally, this method is more efficient when there are many results.

- **Queries that return data: static method.** Specialized SQL Structures (SSQLS) define C++ structures that match table structures in the database schema. This is called "static" method because table structure is fixed at compile time. If some schema changes, update by programmer are required, to update its SSQLS definitions and recompile. In addition the program could crash or throw "bad conversion" exceptions when MySQL++ tries to stuff the new data into an outdated data structure. The advantage of this method is that the program will require very little embedded SQL code. By simply executing a query, results are received as C++ data structures.

2.4.2 +Atleta software

+Atleta software has been developed by using the object oriented programming language Visual C++ [1] and the Microsoft Visual Studio 2005 framework [6]. The implemented application utilizes ActiveX components and the MFC (Microsoft Foundation Class) library. Its programming style follows the guidelines which were expressed in the previous paragraph.

To understand the general software functioning, it is necessary to examine the following information:

- **data organization:** data are divided into three main categories, depending on their function. They could be:

  - log: data from training computers. Each log is referred to a single training session or to a single race. The whole original data set is visualized, and each parameter has its own unit of measurement.
  - Plan: it corresponds to a training model, which can be organized, created or edited.
  - Training Plan: it is a group of different plans, related to a single athlete.

- **Function:** at the moment, the following functions are available, which are grouped by general thematic areas:

  - security: data confidentiality is guaranteed by the initial login procedure that asks the user's name and password. Accounts can be created and subsequently edited. There are two types of account: trainer or athlete. The trainer user can manage personal and all training data (logs) about all the athletes of his team, whereas athlete user can only see his owns. All the user data can be modified or edited or cancelled in any moment.
  - Calendar: by choosing a particular date, it is possible to get an association with more than one Training Plan or simply more than one Plan.
  - Log: it could be imported or exported, through the use of an XML file that stores the data in a structured and fixed way. A log can be modified by the athlete or by his trainer. It is allowed to know which plan is associated with the log, to group more logs under a common root and to split a log in two or more parts. In particular, this is a temporal division.
  - Log comparison: it is possible to compare two different logs; the software shows their parameters' values: maximum, minimum and average value between them.
  - Graphs: the software has lots of different graphic views. It has the goal to show in the best way the training data of any log. It is possible to see only some training data, not the whole data set. This is caused by the fact that

not all running computers store the same information. For example, +Atleta shows parameters like heart frequency, altitude, speed and energy consumption, related to time or to the distance of the training route.

2.4.3 External devices

They represent the entry point for body parameters. Each runner who cooperates in the development of this project, must have a training session using a running computer and every time he/she must transfer data from the device to the PC, because device memory is limited and probably cannot store more than one session's data. In the initial part of the thesis, researches have been operated in order to understand which body parameter could be retrieved from an existing running computer. From a market research, it emerged that there is a large number of running computer producers. In particular, what has been stressed are three important companies which give good warranty about the quality of their products. They are *SUUNTO* [3], *POLAR* [2] and *GARMIN* [1].

Web pages of these companies offer detailed information about technical specifications and features of each model. This made it possible to do a feature comparison between different models. In the following tables, what can be observed are the different technical specifications relating to all the models of the three companies taken into consideration.

It is important to state that in this phase of the project development, not all sports are considered, so we regard only models belong at the RUNNING category.

	SUUNTO								
	X6HR	X3HR	T6	T4	T3	T1	ADVISOR	FOOT POD	GPS POD
Max ventilation			X						
Max oxygen cons.			X						
VO2			X						
Kcal			X	X	X	X			
EPOC			X						
Min HR	X	X	X	X	X	X	X		
Max HR	X	X	X	X	X	X	X		
Average HR		X	X	X	X	X			
Initial time			X	X	X	X			
Finish time			X	X	X	X			
Date			X	X	X	X			
Max speed								X	
Min speed								X	
Average speed								X	
Step number									
Max altitude	X		X				X		X
Min altitude	X		X				X		X
Climb time	X	X	X				X		X
Slide time	X	X	X				X		X
Plan time	X	X	X				X		X
Distance									X
Latitude									X
Longitude									X
Duration			X	X	X	X			
Pressure	X	X	X				X		
Temperature	X	X	X				X		
Lap time	X	X	X	X	X	X	X		

Figure 2.4. Suunto products

	POLAR									
	RS 100	RS 200	RS 200SD	RS 400	RS 400SD	RS 800	RS 800SD	S 625X	S 810I	S1 sensor
Max ventilation										
Max oxyg.cons										
VO2				X	X	X	X	X	X	
Kcal	X	X	X	X	X	X	X	X	X	
EPOC						X	X	X	X	
Min HR	X	X	X	X	X	X	X	X	X	
Max HR	X	X	X	X	X	X	X	X	X	
Average HR	X	X	X	X	X	X	X	X	X	
Initial time	X	X	X	X	X	X	X	X	X	
Finish time	X	X	X	X	X	X	X	X	X	
Date	X	X	X	X	X	X	X	X	X	
Max speed										X
Min speed										X
Average speed										X
Step number										X
Max altitude						X	X	X	X	
Min altitude						X	X	X	X	
Climb time						X	X	X	X	
Slide time						X	X	X	X	
Plan time						X	X	X	X	
Distance										X
Latitude										
Longitude										
Duration	X	X	X	X	X	X	X	X	X	
Pressure										
Temperature						X	X	X	X	
Lap time	X	X	X	X	X	X	X	X	X	

Figure 2.5. Polar products

	GARMIN				
	F101	F201	F301	F205	F305
Max ventilation					
Max oxygen consumption					
VO2					
Kcal	X	X	X	X	X
EPOC					
Min HR			X		X
Max HR			X		X
Average HR			X		X
Initial time	X	X	X	X	X
Finish time	X	X	X	X	X
Date	X	X	X	X	X
Max speed	X	X	X	X	X
Min speed	X	X	X	X	X
Average speed	X	X	X	X	X
Step number	X	X	X	X	X
Max altitude	X	X	X	X	X
Min altitude	X	X	X	X	X
Climb time	X	X	X	X	X
Slide time	X	X	X	X	X
Plan time	X	X	X	X	X
Distance	X	X	X	X	X
Latitude	X	X	X	X	X
Longitude	X	X	X	X	X
Duration	X	X	X	X	X
Pressure					
Temperature					
Lap time	X	X	X	X	X

Figure 2.6. Garmin products

By examining the above tables, it can be noted that the most complete configuration, which gives the major number of parameters, is composed by:

- heart monitor SUUNTO T6;
- SUUNTO foot POD;
- SUUNTO GPS POD;
- management software (SUUNTO training manager).

This equipment provides the user to receive data like *heart frequency* (maximum, minimum and average), *speed* (maximum, minimum and average), *times* (plan, climb, slide and lap), *meteorological data* (pressure and temperature), *geographic data* (altitude) and thanks to the included software it permits to calculate/estimate other useful body parameters including *ventilation*, *oxygen consumption*, *respiratory rate*, *training effect* and *EPOC* (see glossary).

In general POLAR and SUUNTO instruments have similar and comparable features, apart from the data analysis software; the SUUNTO's one is more complex and elaborated and for this reason it allows to perform a deeper and more useful data analysis.

GARMIN products are a little different compared to the previous ones. These are more topography oriented and return high precision data about a training way, included data like *latitude* and *longitude*, *slide*, *climb* and *plan distances* and *times*.

Missing data

Depending on the brand and model of the used training computer, some data cannot be retrieved. This fact entails that +Atleta software can not have at its disposal all parameters, but only a part of them. In particular, only the parameters that they have in common are stored into the database and can be analyzed. This work is focused to add on functionalities and capabilities to the +Atleta software, and to process and analyze these data.

To definitely complete this external device report, the following figures show which are the missing data related on each brand:

	SUUNTO						
	X6HR	X3HR	T6	T4	T3	T1	ADVISOR
Initial time	X	X					X
Finish time	X	X					X
Date	X	X					X
Track profile				X	X	X	
HR data							

Figure 2.7. Suunto missing data

As it has been previously written, SUUNTO T6 heart monitor is the most complete device (only if used with GPS and foot POD). Models X6HR, X3HR and ADVISOR, instead, do not produce data about calendar and training duration, while simpler models like T4, T3 and TX do not provide any topography course data .

	POLAR								
	RS 100	RS 200	RS 200SD	RS 400	RS 400SD	RS 800	RS 800SD	S625X	S810I
Initial time									
Finish time									
Date									
Track profile	X	X	X	X	X	X	X	X	X
HR data									

Figure 2.8. Polar missing data

POLAR products are in general complete about body parameters, but RS100, RS200, RS200SD, RS400 and RS400SD training computer do not allow at all to know information about track profile. RS800SD, RS800SD, S625X and S8101 have some data about track profile, as for example altitude, but they do not provide particular details as GPS coordinates.

	GARMIN				
	F101	F201	F301	F205	F305
Initial time					
Finish time					
Date					
Track profile					
HR data	X	X		X	

Figure 2.9. Garmin missing data

All GARMIN devices have installed a GPS so the exact profile of the training track can be known. GARMIN software does not analyze deeply body data and does not furnish estimated values of EPOC, VO2 and oxygen consumption. Therefore, low level products as F101, F201 and F205 do not store any body data.

Finally, it is important to state that the market research has been made in April 2007, during the initial phase of this thesis, and all the information about the mentioned parameters and device specifications are referred to this date.

Format file

POLAR, SUUNTO and GARMIN products generate data which are the point of departure of the following analysis. Each company develops its own format file, which can be read only by its own software product. In fact, when training session data are transferred from the device to the PC, they are saved as a file. Subsequently, the software opens it and shows the results to the user. More in particular, some details about the different format files are reported:

- POLAR devices produce files with **.hrm** extension;
- GARMIN training computers generate files with **.hst** extension, or, with the new versions **.tcx** one;
- SUUNTO heart monitors use **.sdf** extension.

At the present time, the +Atleta software is not able to take on data directly from devices, but the companies' software have the feature to export their own logs in XML format [7]. So +Atleta can import POLAR, SUUNTO and GARMIN logs thanks to its implemented parsers. It is very important to note that each software has its own XML format. Parsers are used to transform data from each XML file type to a standard XML file used by +Atleta. This is an important feature of the software that reflects the aforesaid project's guidelines, in terms of using standard formal file for every producer. Furthermore, each XML file is different from the other one in terms of:

- kind of stored data;
- number of stored data;
- structural schema;
- precision degree of measurement;
- variable's names;
- meaning of variable's names.

It involves that is essential having an XML structured file equal for all devices. Moreover, it must contain the same information.

The facts just described represent a future works for +Atleta developers, because one of the project's guideline is to achieve the independency between the software and the utilized training computer. So, at the moment, to import a log is necessary to follow these steps:

1. transfer data from device to PC using its own company software;
2. export the selected file in XML format;
3. use +Atleta to standardize XML file and import it.

It is clear that all that has been just described represents a big fault of +Atleta. It must be improved in the future, in order to achieve one of the main fixed points of this project: the simplicity of use.

+Atleta XML format

The XML file has been studied and structured to contain all necessary information, which will be subsequently analyzed, displayed and used to show a simulation of the run way by the program. The file in question contains in addition data to build other files:

- HTML file to visualize data;
- WRL file to see the simulation track.

The XML file (see appendix B.1) shows the utilized structure to store data. The XML schema is basically divided into three main labels, which are:

- **Atleta:** contains all personal data that describe the athlete and his/her physical characteristics; some of them are for example: *sex*, *age*, *height* and *weight*. Furthermore, it contains maximum and minimum values of HR.
- **DadesEntrenament:** information about laps or parts of a single log (training session). In fact, a single log could be split into more laps. It stores data like *speed*, *distance*, *exercise type* and *atmospheric information*.
- **DadesEntrenamentHR:** this section includes the main quantity of data, represented by sample data stored each instant; the sample's number obviously depends on the chosen sampling frequency.

Chapter 3

Statistical software

An important part of this thesis is focused on the creation of a structure able to perform statistical data analysis. The MySQL database only provides simple descriptive statistics, such as maximum, minimum and average value of stored data. In order to perform statistical analysis, it is necessary to use more powerful instruments. After researches, in which all possible solutions have been studied, it has been decided to do not implement any special C++ classes for this purpose, but to utilize an existing statistical software. This approach is the result of the following considerations: to implement every statistical function means to spend much time studying and deeply understanding the functioning of every mathematical instrument that have to be used. Furthermore, there is a high probability of error in development of algorithm calculations. On the contrary, statistical software ensures reliability, a high precision level and provides a large number of simple and complex functions. The last point represents a very important feature, because once the structure has been created, it can be easily adapted and used to new and different statistical analysis. In terms of rapidity, simplicity, precision and future potentiality, to use an existing statistical software guarantees a better result.

A large number of statistical software can be found on the market. In terms of precision level and reliability, there are not so many differences between products like *SPSS*, *MINITAB* or *R*. If others factors are taken into account, the best software for the thesis' purpose is R. It is the only one that has got some particular advantages: it is a free license

and an open-source software, two characteristics that explain its continuous development and improvement by its user community. In fact, R is the most used software by professors and university researchers. Moreover R provides instruments to be remotely used by any custom application. Finally, its simplicity of distribution and its extensive documentation make it the most appropriate choice.

The goal of this chapter is to describe the infrastructure that has been created to embed R in +Atleta project. What has been created is the structure to perform the linear regression of biological data stored into the database. This standard architecture has the great advantage that it can be easily modified to perform all analysis that R allows and to make full use of R capabilities.

3.1 R connectivity

As mentioned in chapter 2, one of the goals of +Atleta project is to create a simulation model, to predict in advance athletes' performances on a particular track. The starting point can be represented by performing a linear regression, to predict a variable knowing another one, using the statistical software R [8]. Obviously, linear regressions have to be strongly embedded in +Atleta context. For this reason, R capabilities and characteristics have been deeply analyzed. A great part of the work related to this thesis is focused on a connection between +Atleta software and R.

R developers created a useful tool to connect R with any custom software; it is called **R SERVER**. The goal in this chapter is to describe what R server is, how it has made connections possible with others programs. Moreover, it aims at explaining which settings and code lines on Visual C++ are needed to use R server under +Atleta. Considering R server as a DCOM server which contains a COM-Interface to R, the first step is to understand the general context and the meaning of these acronyms.

Component Object Model (COM) is a platform for software components introduced by Microsoft [5] in 1993. It is used to enable inter-process communication and dynamic object creation in any programming language that supports this technology. The term COM is often used in software development world as an "umbrella" term that encompasses the OLE, OLE Automation, ActiveX and COM+ technologies. The essence of COM is a language-neutral way of implementing objects which can be used in different environments from the one they were created in. For well-authored components, COM allows reuse of objects with no knowledge of their internal implementation. This is due to the fact that it forces component implementers to provide well-defined interfaces that are separate from the implementation. The different allocation semantics of languages are accommodated by making objects responsible for their own creation and destruction through reference-counting. The preferred method of inheritance within COM is the creation of sub-objects to which method calls are delegated.

Distributed Component Object Model (DCOM) is also a Microsoft proprietary technology for software components distributed across several networked computers to communicate with each other. DCOM extends Microsoft's COM, and provides the communication substrate under Microsoft's COM+ application server infrastructure. DCOM had to solve the problems of:

1. Marshalling: serializing and deserializing the arguments and return values of method calls "over the wire".

2. Distributed garbage collection: ensuring that references held by clients of interfaces are released when, for example, the client process has crashed, or the network connection was lost.

3.2 Embedding R in applications on MS Windows

As mentioned before, COM/DCOM objects define a standard for interoperability and their function is assumed to be comparable with the one of a library. This kind of programming technique, similar to the *object-oriented* paradigm, is more specifically called *component-oriented*. A component is fundamentally a basic unit that can encapsulate operations (*methods*), data (*properties*) and state; it manages life-cycle by reference counting and perform object creation.

It is important to know the right nomenclature:

- a component is called "COM/DCOM server";
- a user of component is called "COM/DCOM client".

The R SERVER package contains a DCOM server used to connect a client application with R. As it was previously said, the R SERVER package provides a COM-Interface to R as well as various COM objects and ActiveX controls do for many applications. R (D)COM server has got a mechanism for:

- standard applications (like Microsoft Excel);
- custom applications written in any language to serve as a COM/DCOM client; they use R as a powerful computational engine and renderer for graphics and text output.

After this general introduction, it is important to understand which the basic elements that compose the R connectivity to +Atleta software are and in which way they are related. The following figure shows the connections between R client, R server and R [11]:

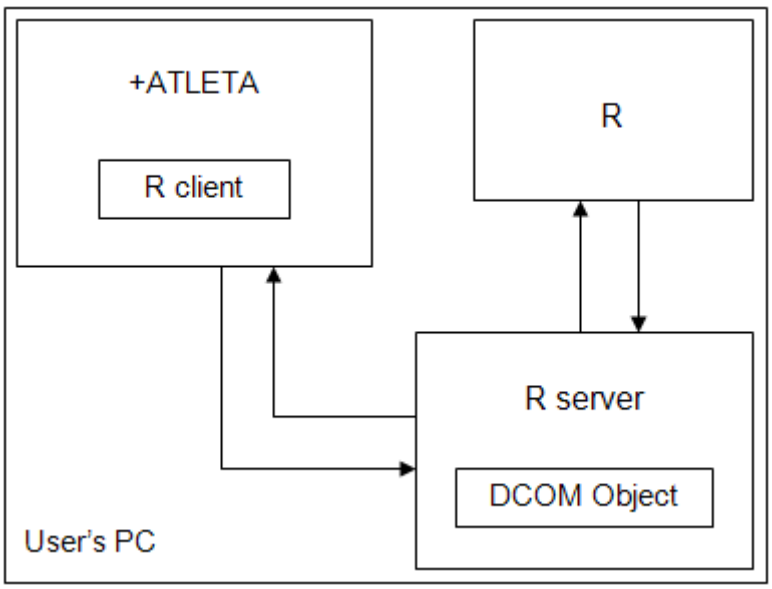


Figure 3.1. R connectivity structure

As can be observed from the picture above, the connection heart is R server, which joins R[1] and the software +Atleta. +Atleta represents a R client, and it can access to the R engine only by R server. This last component controls and manages the access to R if there are more clients at the same time.

In order to give a summary of what has been said before, main features of the package R DCOM SERVER are the followings:

Use: thanks to the COM and DCOM technologies, it is possible to set R for local and remote use respectively. DCOM allows transparent use of remote components and application does not have to be changed for remote use. By paying attention to the configuration settings on COM client's and on COM server's computer, it is possible to obtain user synchronization. To synchronize means that a given component lives in a space that could be called "apartment" (comparable to *thread* context) and execution context of a method call is always the component's apartment. Into this apartment, all method calls are synchronized, but it is not allowed to have parallel

[1]It is required that R statistical software is installed on the computer.

computations on a single R "instance". In particular, this thesis' work is focused only on local use.

Data transfer: both from R to the client-application and vice versa, currently supporting scalars (like *booleans*, *integers*, *doubles* and *strings*), arrays of these and arrays of mixed data types (for example *booleans* and *strings* in a single array). Only one array at a time can be past because the use of array of arrays is forbidden.

Text and graphics output: they are captured by using special ActiveX controls. They allow to store outputs into particular data structures and subsequently import them in the developed custom application.

Multiple local/remote server applications: the current implementation of the R server package puts every single R interpreter used in a client application into a separate address space. It also allows different code and data segments for multiple instances of the interpreter even in a single client instance.

Multiple local/remote clients: using COM/DCOM to expose R's functionality to client applications even makes it possible to share a single instance of an R interpreter between multiple client applications, both running on the same or even on different machines in the network. Sharing an interpreter instance also implies a shared data and code segment for R. The implementation using COM takes care of synchronizing access to the interpreter, so only one client can use the server's functionality at the same time.

Finally, it is important to state that clients and servers can communicate only using COM/DCOM objects. COM/DCOM object is the media that allows communications and data exchanges. It is composed by two parts:

- **COM interface,** which contains *methods* (functions and operations) and *properties* (variables) visible by clients. It also contains its internal state, that is invisible by clients. This interface represents the unique entry point to the object; an important characteristic is that it must not be changed at all, even new methods cannot be implemented. Given that it is an interface, it has an abstract definition and it is identified by its IID (Interface IDentifier), a 128 bit numeric value.
- The second element is called **Coclass**, which is the implementation of COM interface. As many programming languages allow, even in this case, multiple Coclasses can implement the same interface. Unlike the COM interface, the Coclass is identified by its CLSID (CLass IDentifier), a 128 bit numeric value or, more simply, by its name. Coclass is referred to a COM client, who is programmed against interface, and this reference is established at run-time.

3.2.1 Interface IStatConnector

IStatConnector interface is a COM interface that allows users to connect to R and exchange information with it. In fact IStatInterface defines the methods used to access to R. Its structure is very simple, as the following example code shows. They are divided into three thematic blocks:

Figure 3.2. IStatConnector interface

Referring to the code above, the following flowchart represents life-cycle of a COM object that uses the IStatConnector interface:

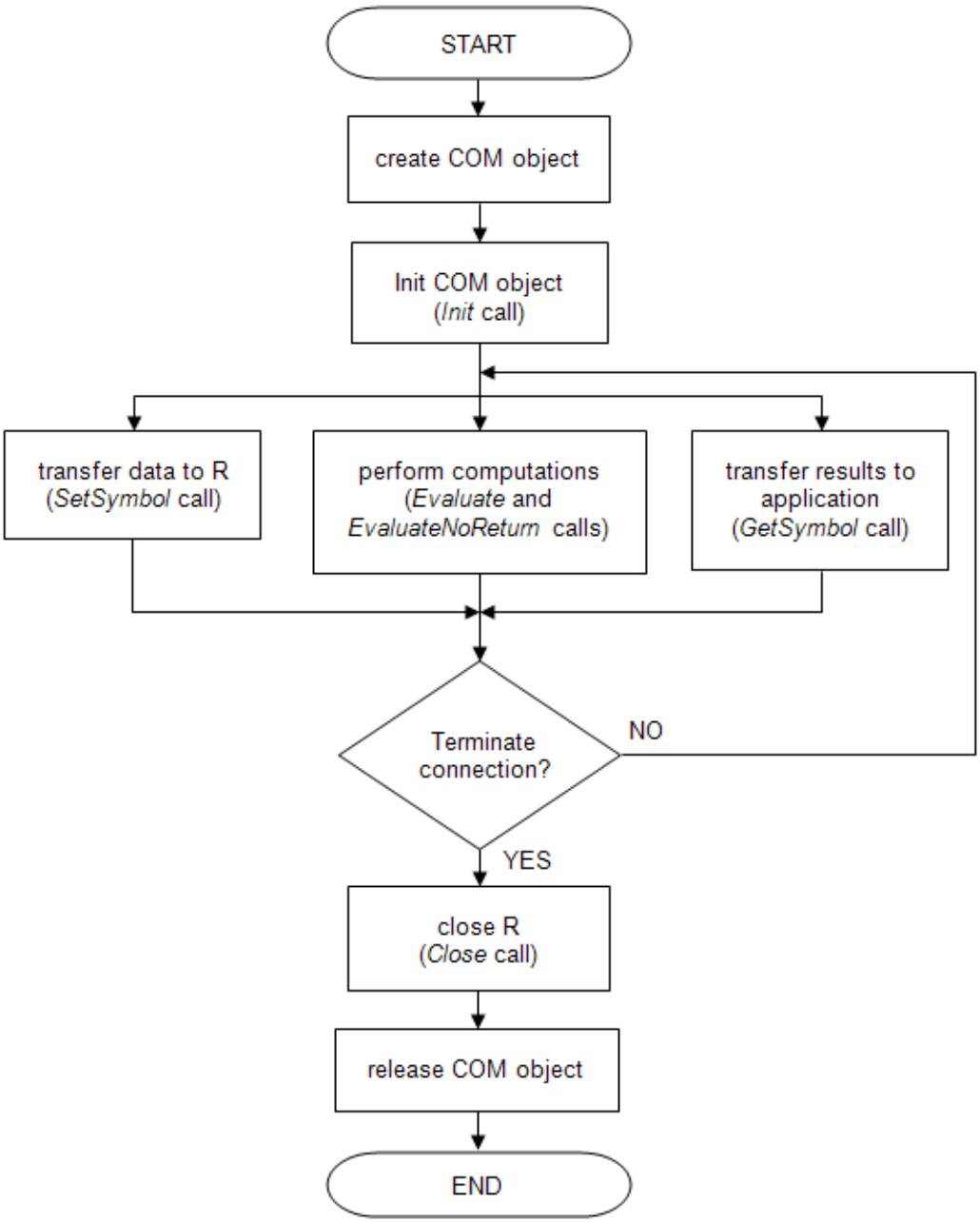


Figure 3.3. COM object life-cycle

With the implementation of IstatConnector, it can be noted that all the components involved assume a different role. On the one hand, **R Server** runs R in "background", it means that it is invisible by the user, while every objects gets its own process because they have different symbol spaces in R server. R server also provides to redirect the R graphic and textual outputs. On the other hand, **R client** runs R in "foreground" and user can use R in parallel to many applications. Furthermore, every object accesses the same R process, that is unique and allows one object access at a time, each one only in its shared symbol space. In this context, textual and graphic output can be displayed in a window. Finally, both **Coclasses** implement more COM interfaces and the application can use any of them. Different CLSID are used in order to distinguish between them.

3.2.2 Data transfer

Unique allowed data transfer format is called VARIANT. The peculiarity of this format is that it can contain any type of data, and this is determined by the VARIANT's type (VT). The main characteristics of VT are the followings:

- scalar values are supported. In particular:
  - VT_BOOL, VT_I2, VT_I4, VT_UI1, VT_R4, VT_R8, VT_BSTR;
  - VT_EMPTY;
  - VT_ERROR (xlErrDiv0, xlErrNA, xlErrNull).
- Arrays of same scalars of any dimensions represent the optimized data transfer mode;
- arrays of different scalars generate the "mixed transfer mode", who is not as efficient as the previous one.

COM Object can be transferred from application to R and vice versa. It simply utilizes IStatInterface's methods already described. Moreover, COM Object made possible to send data and retrieve a particular operation or analysis on that. Furthermore, R text

output and R graphic output can be retrieved using two different ways, starting from the fact that R (D)COM Server allows redirection of text and graphics output:

- Using ActiveX control for capturing text and graphic output available;
- Using COM object for (programmatically) capturing text output available.

In this project, the ActiveX approach has been used because it allows a greater simplicity of use and a more intuitive understanding. For this reason, additional functions exist in IStatConnector Interface:

```
IStatConnector : IDispatch
{
...
HRESULT AddGraphicsDevice([in] BSTR
bstrName,[in] ISGFX* pDevice);
HRESULT RemoveGraphicsDevice([in] BSTR
bstrName);
...
HRESULT SetCharacterOutputDevice([in]
IStatConnectorCharacterDevice* pCharDevice);
...
}
```

Graphic output

Text output

Figure 3.4. Interface IStatConnector's output

3.2.3 Error handling

It is based on the assumption that every function returns an HRESULT result. For this reason, standard COM error handling mechanism exist, which uses the macros SUCCEEDED() and FAILED() to check errors in functions. At the moment, it could be considered a great fault because the mechanism of error handling is not so easy and simply to manage and utilize. The most effective example is that errors in every function call must be checked. Anyway, to ensure the completeness, the following table quotes the most common error codes:

PREPROCESSOR DEFINE	VALUE	DESCRIPTION
SCN_E_INITIALIZED	0x8004005	Init not called
SCN_E_NOTINITIALIZED	0x8004006	Init already called
SCN_E_INVALIDSYMBOL	0x8004007	symbol not found
SCN_E_PARSE_INVALID	0x8004008	invalid expression
SCN_E_PARSE_INCOMPLETE	0x8004009	incomplete expression
SCN_E_UNSUPPORTEDTYPE	0x800400A	data type not supported
SCN_E_EVALUATE_STOP	0x800400B	evaluation stopped because of an error
SCN_E_INVALIDINTERFACEVERSION	0x8004010	interpreter interface version mismatch (Rproxy does not match R (D)COM Server)
SCN_E_INVALIDINTERPRETERVERSION	0x8004011	interpreter version mismatch (reserved for future use)
SCN_E_INTERFACENOTFOUND	0x8004012	reserved for future use
SCN_E_LIBRARYNOTFOUND	0x8004013	rproxy.dll could not be loaded
SCN_E_INVALIDLIBRARY	0x8004014	invalid rproxy.dll
SCN_E_INITIALIZATIONFAILED	0x8004015	initialization failed
SCN_E_INVALIDCONNECTORNAME	0x8004016	connector name "R" expected
SCN_E_INVALIDINTERPRETERSTATE	0x8004016	reserved for future use
SCN_E_FATALBACKEND	0x8004020	access violation in R (interpreter, package code)
SCN_E_INVALIDARG	0x8004001	reserved for future use
SCN_E_INVALIDFORMAT	0x8004002	reserved for future use
SCN_E_NOTIMPL	0x8004003	reserved for future use
SCN_E_UNKNOWN	0x8004004	reserved for future use

Figure 3.5. Error handling

3.3 R connection example

The following lines represent a sample C++ code that helps to immediately understand what has been described until now:

```
#include "statconnectorsrv.h"
#include "statconnectorcharacterdevice.h"
#include "statconnectorgraphicsdevicectl.h"

class exampleClass
{
//DECLARATIONS of IStatConnector, textual and graphic devices
IStatConnector lConnector;
IDispatch* lCharDev = NULL;
IDispatch* lGfxDev = NULL;

//devices connection controls
if(FAILED(m_CharDev.GetControlUnknown()-
>QueryInterface(IID_IDispatch,(LPVOID*) &lCharDev)))
  {
    MessageBox("Error querying Dispatch from Character Device");
    return;
  }

 if(FAILED(lConnector.CreateDispatch(_T(
 "StatConnectorSrv.StatConnector"))))
  {
    MessageBox("Error creating StatConnectorSrv");
    return;
  }

//first R call
lConnector.Init(_T("R"));

//DECLARATIONS of class variables and values settings
VARIANT lVal1,lVal2,lVal3;
VariantInit(&lVal1);
VariantInit(&lVal2);
VariantInit(&lVal3);
V_VT(&lVal1) = VT_R8;
V_VT(&lVal2) = VT_R8;
V_VT(&lVal3) = VT_R8;
V_R8(&lVal1) = 12;
V_R8(&lVal2) = 4;
V_R8(&lVal3) = 0;

//ACTIVE X initialization
lConnector.SetCharacterOutputDevice(lCharDev);
lConnector.AddGraphicsDevice(_T("Gfx"),m_GraphDev.GetGFX());
```

```
46  //R initialization variables
47  lConnector.SetSymbol("uno",lVal1);
48  lConnector.SetSymbol("due",lVal2);
49  lConnector.SetSymbol("tre",lVal3);
50  //R computation
51  lConnector.EvaluateNoReturn(_T("tre=uno+due"));
52
53  //retrieving variable from R
54  double returnValue=lConnector.GetSymbol("tre").dblVal;
55
56  //graph and text capture
57  lConnector.EvaluateNoReturn(_T("plot(tre*1:100)"));
58  lConnector.EvaluateNoReturn(_T("cat(tre)"));
59
60  //resource releasing
61  lConnector.Close();
62  lConnector.ReleaseDispatch();
63  lConnector.RemoveGraphicsDevice(_T("Gfx"));
64  }
```

Figure 3.6. Example

A close examination of same passage is needed:

LINE	DESCRIPTION
1 to 3	Inclusion of the R server, text Active X connector and graphic Active X connector headers.
32 to 45	Local class variables declaration and setting. They are defined as `VARIANT`, `VT_R8` that can be associated to the more common `double` type. Only by defining them as `VARIANT`, it is possible to pass them to the R computational engine.
47 to 49	These lines represent the data exchange from the class to R. For example the code of the line 47 generates a R variable called `uno` and its value is the same of `lVal1`. Notice that not exist any connection or synchronization between the two variables: the first belong to the R environment while the second is local and belong to the class. Any change of one of them does not have any repercussion on the other one.
51	This method is utilized to send commands to the R engine. Commands submitted are exactly the same that one uses in the R prompt console. In this way R calculates `tre` as sum of `uno` and `due`.
54	By using this method is possible to retrieve the variable's value from R.
57	All graphs invoked by code and subsequently generated by R are captured by the special Active X control. Including it into a normal dialog box it is possible to see the graphs.
58	All R textual output is captured and shown by the other Active X control, who exactly works in the same way of the graphic one.
61 to 63	Resource releasing. It is really important to notice that only one Active X control at the same time can be used (obviously of the same type).

Figure 3.7. Notes

3.4 Linear regression's theory

As mentioned in chapter 2, one of the goals of +Atleta project is to create a simulation model, in order to predict in advance athletes' performances on a particular track. The starting point can be represented by performing a linear regression, to predict a variable knowing another one, by using the statistical software R. In this section, the linear regression's theory is explained as well all passages that have to be followed to perform a linear regression with R.

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, the other is considered to be a dependent variable.

A linear regression line has an equation of this form:

$$y = mx + b \tag{3.1}$$

where

- x is the explanatory variable;
- y is the dependent variable;
- m is the slope of the line;
- b is the intercept (the value of y when $x = 0$).

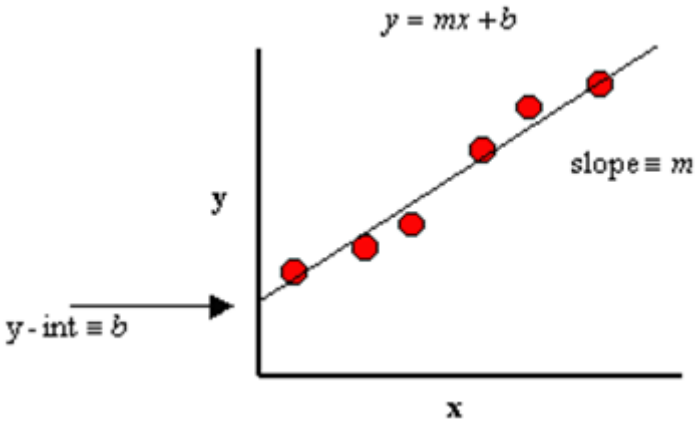


Figure 3.8. Linear regression line

The slope quantifies the steepness of the line. It equals the change in y for each unit change in x. It is expressed in the units of the y-axis divided by the units of the x-axis. If the slope is positive, y increases as x increases. If the slope is negative, y decreases as x increases. The y intercept is the y value of the line when x equals zero and it defines the elevation of the line.

The goal of linear regression is to adjust the values of slope and intercept in order to find the line that best predicts *y* from *x*. The most common method for fitting a regression line is the method of **least-squares**.

More precisely, this method calculates the best-fitting line for the observed data by minimizing the sum of the squares of the vertical deviations from each data point to the line (if a point exactly lies on the fitted line, then its vertical deviation is 0). Since the deviations are first squared, then summed, there are no cancellations between positive and negative values.

In order to better understand the working of this method, in this page are reported the formulas that have to be used to perform a statistical treatment to the data. Given a set of data (x_i,y_i) with *n* data points, the slope (*m*) and y-intercept (*b*) can be determined using step by step the following formulas:

x average value:

$$\mu_x = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{3.2}$$

y average value:

$$\mu_y = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{3.3}$$

$VAR(x)$:

$$\sigma_x^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i^2 - \mu_x^2) \tag{3.4}$$

$VAR(y)$:

$$\sigma_y^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i^2 - \mu_y^2) \tag{3.5}$$

$COV(x,y)$:

$$\sigma_{xy} = \frac{1}{n}\sum_{i=1}^{n}[(x_i y_i) - (\mu_x \mu_y)] \tag{3.6}$$

Correlation coefficient:

$$r_{xy} = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \tag{3.7}$$

Slope:

$$m = \frac{COV(x,y)}{VAR(x)} = \frac{\sigma_{xy}}{\sigma_x^2} \tag{3.8}$$

y-intercept:

$$b = \mu_y - m\mu_x \tag{3.9}$$

Note that linear regression does not test whether the data are linear. It assumes that data are linear, and finds the slope and intercept that make a straight line which best fit the data. For this reason, it is necessary to find parameters which give a measure of correctness of fit of linear regression. A valuable numerical measure of association between two variables is the **correlation coefficient**, r_{xy}. It is a value between -1 and 1 indicating the strength of the association of the observed data for the two variables. The correlation coefficient, gives a measure of the reliability of the linear relationship between the *x* and *y* values. A value of $r_{xy} = 1$ indicates an exact linear relationship between *x* and *y*. Values of r_{xy} close to 1 indicate excellent linear reliability. If the correlation coefficient is relatively far away from 1, the predictions based on the linear relationship, $y = mx + b$, will be less reliable. Some examples are present in the next page.

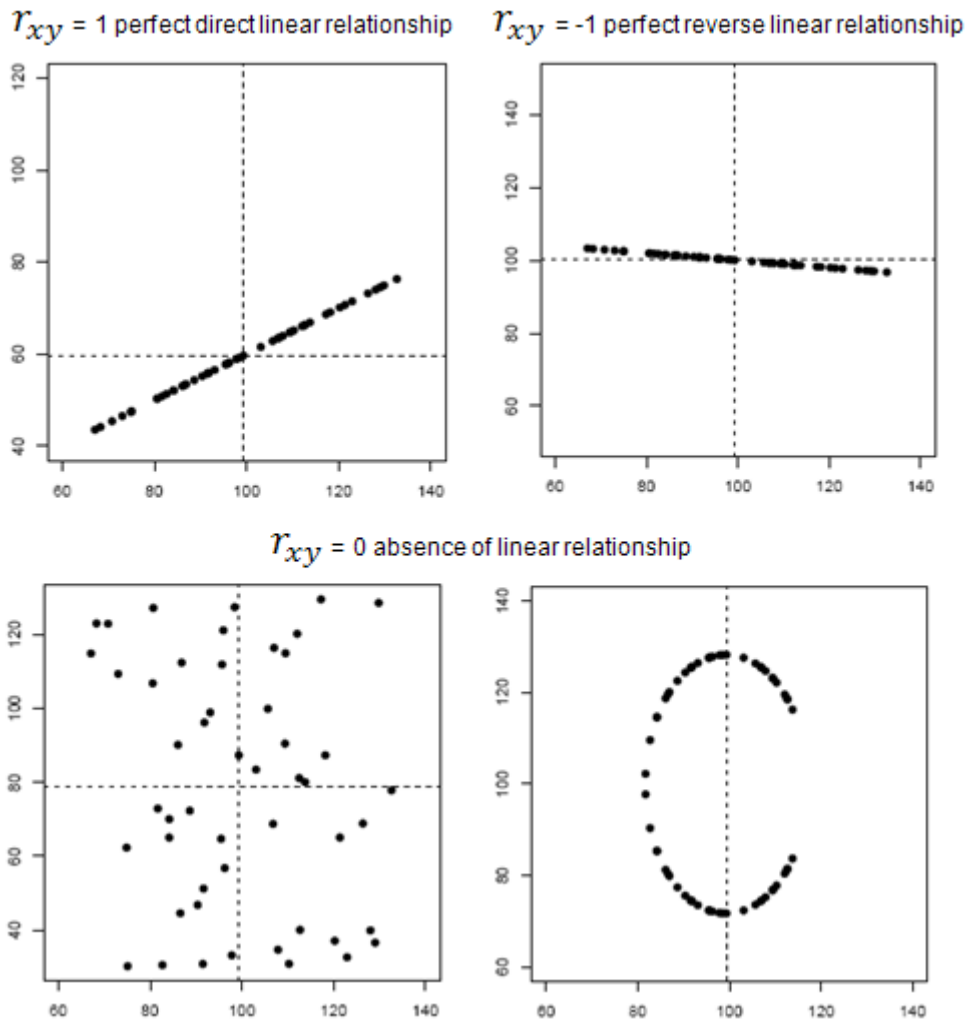


Figure 3.9. Correlation coefficient

There is another parameter that functions exactly as the correlation coefficient. It is called **coefficient of determination** and its symbol is r^2. In the simple linear regression it is the square of the correlation coefficient. The value r^2 is a fraction between 0.0 and 1.0, and has no units. An r^2 value of 0.0 means that knowing x does not help to predict y. There is no linear relationship between x and y, and the best-fit line is a horizontal line going through the mean of all y values. When r^2 equals 1.0, all points lie exactly on a straight line with no scatter. Knowing x let predict y perfectly. For example, a r^2 value of

0.726 indicates that 72.6% of the variation in one variable may be explained by the other.

Finally, it is very important to remember that the absence of linear relationship between variables does not mean that any relationship between them does not exist.

3.5 Linear regression using R

Modern statistical software can execute steps described in the previous paragraph automatically, performing calculation in few instants. In particular, by using the statistical software R, a linear regression can be performed following these few passages [12]:

1. data set declaration: each data set has to be filled in vectorial form;
2. linear regression command: using the command `lm`, it is possible to perform the linear regression between variables;
3. data set display: typing `plot` it is possible to obtain a graphic representation (scatterplot) of the used data set;
4. fitting line display: the `abline` command is used to display the calculated fitting line;
5. show results: the `summary` command is useful to show all information about the linear regression just performed.

The following example is useful to understand immediately previous points:

```
x:  1  2  3  4  5  6  7  8  9 10 11 12
y:  23.0 21.5 22.1 21.9 21.8 21.4 22.5 22.3 22.4 22.3 22.2 22.9
> result <-lm (y ~ x)
> plot (x, y, col="4")
> abline (result, col="2")
> summary (result)
```

Given the data set (x,y), R produces two kinds of output:

1. Graphic output: it is composed by the scatterplot of the data set and the fitting line.

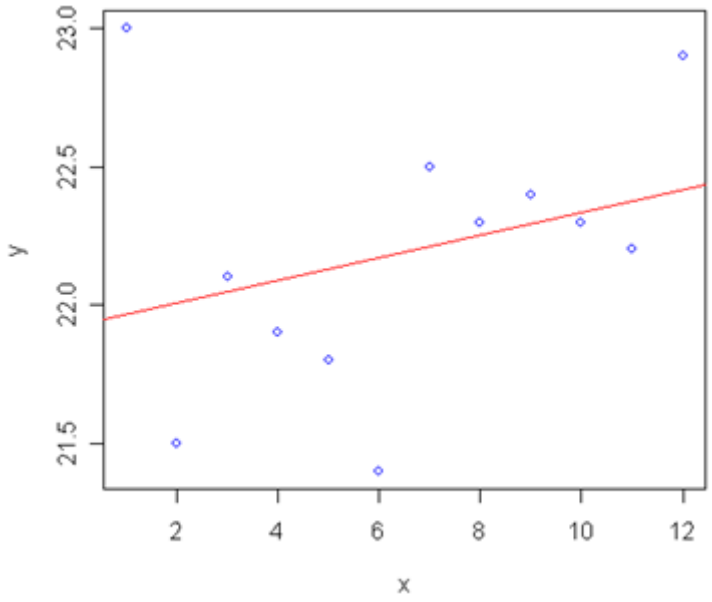


Figure 3.10. R graphic output

2. Textual output:

```
Call:
lm(formula = y ~ x)

Residuals:
      Min        1Q    Median        3Q       Max
-0.771212 -0.224621  0.006061  0.151515  1.033333

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 21.92576    0.30338  72.271 6.28e-15 ***
x            0.04091    0.04122   0.992    0.344
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4929 on 10 degrees of freedom
Multiple R-Squared: 0.08966,    Adjusted R-squared: -0.001374
F-statistic: 0.9849 on 1 and 10 DF,  p-value: 0.3444
```

As can be observed, the textual output is composed by numerous lines, each one containing statistic information and estimated parameters. In particular, there are two values that assume great importance to verify the correctness of the used method:

- **Multiple R-Squared:** already described, also called coefficient of determination, it represents a valuable numerical measure of association between variables;

- **P-value:** in statistical hypothesis testing, is the probability of obtaining a result at least as extreme as a given data point, under the null hypothesis. The fact that p-values are based on this assumption is crucial to their correct interpretation. It is a probability, so its value is a fraction between 0.0 and 1.0.

It has been introduced a new term: the **null hypothesis** [6]. It is a hypothesis set up to be nullified or refuted in order to support an alternate hypothesis. When used, the null hypothesis is presumed true until statistical evidence in the form of a hypothesis test indicates otherwise. This means that the null hypothesis proposes something initially presumed true. It is rejected only when it becomes evidently false. That is, when one has a certain degree of confidence, usually 95% to 99%, the data does not support the null hypothesis.

Formulation of the null hypothesis is a vital step in testing statistical significance. Having formulated such a hypothesis, the probability of observing the obtained data or data more different can be established from the prediction of the null hypothesis, if the null hypothesis is true. That probability is what is commonly called significance level of the results. Generally, one rejects the null hypothesis if the p-value is smaller than or equal to the **significance level**. In this case, the null hypothesis is formulated when the method of least-squares is applied.

Given the model in the following form:

$$y_i = \beta_0 + \beta_1 x_i \tag{3.10}$$

As aforesaid, the aim of this method is to calculate the values of β_0 and β_1 that minimize:

$$\sum_{i=1}^{n}(y_i - \beta_0 - \beta_1 x_i)^2 \tag{3.11}$$

The null hypothesis is:

$$H_0 : \beta_1 = 0 \tag{3.12}$$

It follows that the **alternate hypothesis** is:

$$H_1 : \beta_1 \neq 0 \tag{3.13}$$

Calling α the significance level, it is possible to have only two scenarios:

if $\alpha <$ p value $\quad H_0$ is accepted
if $\alpha >$ p value $\quad H_0$ is rejected

Normally, if H_0 is rejected, the linear regression fits the given data set.

Final clarifications are needed because there are several common misunderstandings about p-value. Here the most frequents are reported:

1. The p-value is **not** the probability that the null hypothesis is true (claimed to justify the "rule" of considering as significant p-values closer to 0). In fact, it is not possible to attach probabilities to hypotheses.

2. The p-value is **not** the probability of falsely rejecting the null hypothesis.

3. The p-value is **not** the probability that a replicating experiment would not yield the same conclusion.

4. 1-(p-value) is **not** the probability of the alternative hypothesis being true.

5. The significance level of the test is **not** determined by the p-value. The significance level of a test is a value that should be decided upon by the agent interpreting the data before the data are viewed. It is compared against the p-value or any other statistic calculated after the test has been performed.

6. The p-value does **not** indicate the size or importance of the observed effect.

Finally, in appendix B.3 is present the programming code of +Atleta that performs the linear regression of two variables by using R and that shows R's graphic and textual outputs.

3.6 Biomedical motivations

At the moment, in +Atleta software only few linear regressions have been performed. The following lines explain the motivations and the information that can be retrieved from them [14]:

1. HR - SPEED: it represents one of the most important factors. In fact, the knowledge of the relation between HR and speed is very important to estimate the *athletic training level* of a person. Observing this parameter, it is possible to know if it is necessary to modify current training sessions to improve the athlete's performance or not. For example, to have a high speed and a relatively low HR is index of a great athletic training level. This is due to the fact that it means that the athlete can run faster with a lower energy consumption.

2. HR - ALTITUDE: a factor that can be observed is the *body altitude adaptability*. At high altitude (about 2000 m) to do physical activity is more exertive; this is due to the decreasing of oxygen concentration in the air. Less oxygen availability usually entails the increasing of HR and respiration rate, too. This is the body natural behavior to maintain a constant level of oxygen in the system for a short period. Another typical body reaction (usually at higher altitudes, over 2000 m) is the red blood cell increasing, to transport more oxygen quantity.

3. HR - DISTANCE: its progress indicates if an athlete is trained enough to large distances. This is a secondary factor compared to the first ones, but, anyway, it represents an aspect that does not have to be forgotten. For example, if the athlete's HR significantly increases after a certain covered distance, this could imply wrong training plans for long distances.

4. SPEED - ALTITUDE: this parameter is very similar to the HR - ALTITUDE one, described at the point 2. This is due to the fact that maintaining a high speed on a high altitude entails a stronger HR increasing than at lower altitudes. A very interesting analysis could be to compare performances at different altitudes (with a significant gap), and to observe the speed variations in both cases.

5. SPEED - ENERGY: this factor relates speed and energy consumption. It assumes significance only if it is associated with HR, DISTANCE and GRADIENT values. It is very particular, because it does not give a physical parameter, but a psychological one. It signals if a runner feels at ease running to a certain speed or not. It happens that some athlete prefers run at low speed, also for very long distances; others, for example, do not feel at ease running fast on a slope or they spend too much energy on a climb. In all these cases, energy consumption value changes.

6. SPEED - DISTANCE: this data has to be associated to the HR - DISTANCE analysis [15]. It indicates the body behavior, especially on long distances. It can be interesting to understand if a runner knows how to manage a long distance race, rationing his/her forces and energy to maintain a constant performance or not.

Chapter 4

Analysis algorithms

4.1 Exertion algorithm

In order to be effective and to cause an adaptable response, a training session must in some way cause disturbance in the body's internal balance. This particular phenomenon is called "homeostasis". Any physical exercise per se is exertive and deteriorates performance, but after training, during the *recovery phase*, the body is being "built up". The body adapts to the requirements of exercise in order to be able to perform that task again. Actually, the body is "built up" a little better than it was before, a phenomenon known as "supercompensation".

To know the supercompensation level and the right training frequency, it is important to estimate how exertive are training sessions. The method which has been utilized in this thesis in order to calculate exertion, is the same suggested in the POLAR Precision Performance software manual [2].

Another important factor to consider is the time required for recovery. It foremost depends on the intensity (HR) of the training session and also on the duration of this session. For athletic training, it is essential to schedule training sessions at correct intervals: not too close to each other in order to avoid overtraining and not too far from each other in order to avoid undertraining. However, it is difficult to evaluate the effects of both intensity

and duration in respect of the recovery time needed. Until now, it has been difficult to estimate the time needed for recovery after training sessions when athletic training consists of several different types of training.

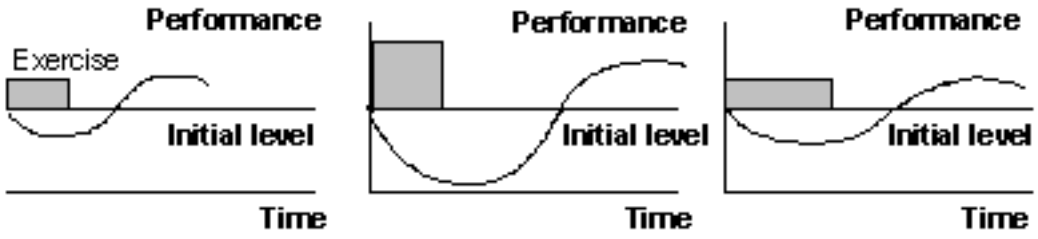


Figure 4.1. A schematic presentation of the acute effects of an exercise bout on performance. The vertical axis depicts the intensity and the horizontal axis shows the duration of an exercise

As can be seen from the previous schema, the immediate effect of an exercise is a decrease in the performance level. After the exercise, a recovery phase occurs and the performance curve slightly rises above the initial level. This phenomenon is exactly the supercompensation. Thus, for a short and certain period of time after the exercise session, the performance improves to a level slightly higher than it was before that exercise session. This phenomenon is the basis of all training programs. The next training session should occur during the supercompensation phase. Then, it is possible to gradually increase performance, starting each time from a slightly higher level. However, if the next exercise comes too early, the performance level will decline even more, and the recovery will take longer. Respectively, if the next session is delayed, and is done when the supercompensation phase is over, the net effect of multiple sessions will be close to zero. The exertion count is designed to make all exercise sessions measurable referring to sport, duration and intensity level.

As mentioned before, the most useful information from the exertion count comes when one learns to relate his/her exertion level to the time needed for recovery after a single training session. The figure in the next page shows a schematic view of the suggestive relationship between exertion and recovery time. The values used are personalized.

Therefore, a record of his/her own experiences and findings should be kept for several weeks before applying this analysis.

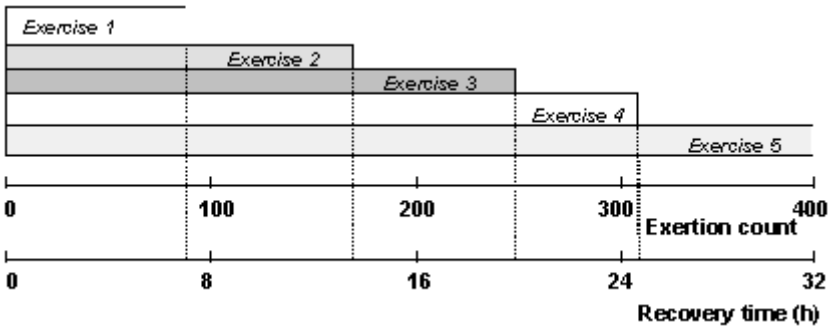


Figure 4.2. A schematic relationship between exertion count and recovery time

The previous figure shows, for example, that for a exertion value of about 300, the related recovery time is of about one day. Past this time, the athlete is able to perform a new training session, because his/her body is in the supercompensation phase. When one has found out how his/her own exertion factors relate to recovery, he/she can easily control his/her training in advance. It is also possible to know after each session when he/she is able to start the next one. The exertion count rapidly reveals when easy days have come and if the load has been constant or inconstant.

The heart rate level achieved during light recovery exercises accurately demonstrates the body's exertion level. When recovery has been unsuccessful, the heart rate tends to rise and speed to decrease. In addition to heart rate and speed, subjective feelings during the exercise are also an essential part of evaluating the exertion level. All three variables - heart rate, speed and feelings - describe the exertion level. Sometimes changes are apparent in only one of the above factors. When heart rate, speed and feelings are regularly monitored during light and recovery exercises, the athlete is able to immediately react to changes in the above factors. This ensures optimal development and helps to avoid overexertion. The graph in the next page can be observed in order to clarify this concept. The graph compares two exercises performed in two different states of recovery. The

objective of the exercises has been to perform a steady-paced light run. Moreover, the exercises have been performed in the same place. The lower heart rate curve corresponds to an exercise performed after proper recovery. The athlete's subjective feeling has been good. The average heart rate is 127 bpm and speed 4.26 min/km. The upper heart rate curve corresponds to an exercise that was felt to be difficult. The average heart rate is 137 bpm and speed 4.30 min/km. The heart rate curves show a distinct difference in the state of recovery. The situation demonstrated by the upper curve is due to heavy training during the days prior to the test. It is important to state that increased heart rate level during light aerobic training may also be caused by other factors, such as flu.

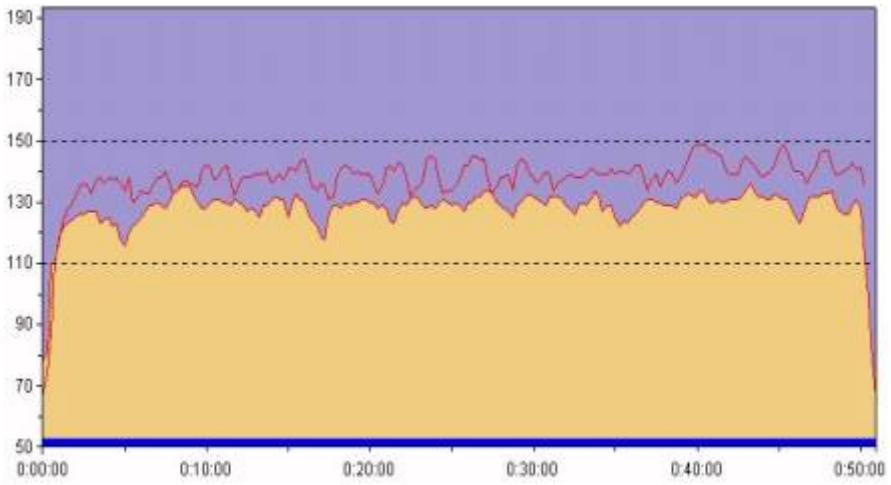


Figure 4.3. Heart rate curves comparing recovered situation vs. strained/tired situation

4.1.1 Calculating the exertion count

The exertion count has been developed to ease and simplify the analysis of athletic training programs. It combines three factors of a training session into a single measurable figure:

1. duration (time, expressed in minute);

2. intensity (heart rate, expressed in beats per minute);
3. sport factor (constant depending on the sport).

For each training intensity interval (HR interval), is given an exertion factor by which the time spent at that HR is multiplied. Some exercise modes or sports have their additional impact on the exertion and thus a sport factor is applied. The exertion count is the total sum of these three components. Its formula is the following one:

$$Exertion = \sum_{i=0}^{n}[(EF\,of\,HR\,interval) \cdot (time\,spent\,in\,that\,interval)] \cdot (SF) \quad (4.1)$$

where:

- *EF* is the Exertion Factor;
- *SF* is the Sport Factor;
- *i* is the index of the HR interval;
- *n* is the number of HR intervals.

The concept of exertion count is easy to understand with the help of the chart of the next page. The chart describes relative exertion as a function of exercise heart rate. The higher the heart rate, the harder is the exercise. It is easy to agree that 30 minutes of exercise at HR of 160 beats/min is about twice as exertive as 30 minutes at HR of 140 beats/min. The exertion count is a simple way to express the total exertion of a single training session as a combination of the intensity and duration of exercise. The exertion count values are typically from 50 - 400. At these magnitudes, they are easy to use in simple calculations.

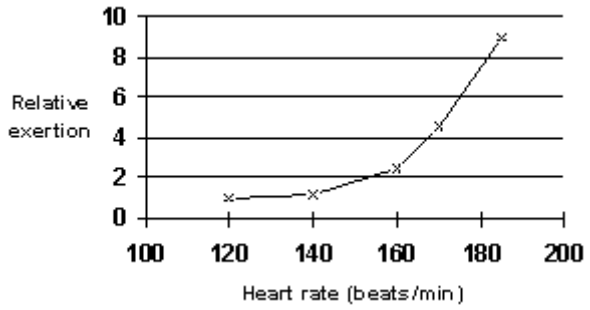


Figure 4.4. The relative exertion of an exercise as a function of heart rate

A last consideration has to be done about sport factors. The definition of sport factors is targeted at an advanced user of the software. As can be seen from the following statements, several factors are involved when determining an appropriate factor for a certain sport. The basic assumption is that each individual has his/her favorite sport which is most often used. The following presents a selection of the most popular sports and recommendations for their sport factors. The recommended factors range within 0.8-1.3, thus being of relatively minor importance, and therefore emphasize the importance of HR measurement in all training sessions.

Running/jogging 1.0

Running is expected to be the most common sport, and thus has the factor 1.0 to which other sports are related.

Aerobics 0.9-1.1

The correct factor of aerobics depends very much on the type of a particular program. Typically aerobics consists mainly of dynamic movements mainly involving lower extremity muscles. Also, the recovery phases, if there are any, are relatively short. The differences between step/low/high/combo are mainly reflected in HR.

Cycling 1.1-1.2

To reach the same HRs, one will have to work approximately 10 to 15% harder in cycling than in running. That is mainly due to the slightly slower frequency of cycling, the lack of a weight bearing task in cycling and the larger amount of eccentric work in running.

Mountain biking 1.0-1.1

Mountain biking differs from road cycling as regards the usage of upper body muscles and the amount of standing. Also, the varying terrain makes the demands of mountain biking somewhat higher than those of road cycling but mostly these differences are also reflected in the HR.

Stepping 1.0-1.2

As to the sport factor, stepping is very much like cycling, as it lacks the eccentric component of work, yet requires a relatively large muscle mass. However, the rhythm of work may impair circulation and thus cause an increase in blood lactate. This, in turn, may not be reflected in the HR and should therefore be taken into account in the sport factors.

Canoeing, paddling 1.2-1.3

This is a typical upper body exercise. For an occasional canoeist high HRs are difficult to reach, but the upper body may be rather exhausted, because the work is done by a limited muscle mass.

Rowing 0.9-1.2

See cycling and stepping. However, the involvement of upper body may cause effects such as in cross-country skiing.

Walking 1.1

Walking is similar to biking in regards to the effort for reaching a given HR. Again, this is due to the mainly concentric work of muscles. Also walking lacks the rapid and large limb movements which per se increase HR.

Swimming 1.2-1.3

For a recreational swimmer high HRs are difficult to reach, giving swimming a high factor. The respiratory muscles are highly stressed, which is also the case with upper body and hip muscles.

Tennis 1.0

Tennis is a game in which rapid movements and the work of the whole body are combined with relatively long pauses. This combination allows your HR to react quite precisely so that additional factors may not be needed.

Badminton 1.1-1.2

The abrupt nature of badminton makes your HR rise relatively easily. However, the energy production lies mainly on carbohydrates and anaerobic energy yield without adequate respiratory stimulus, and leads into a slight underestimation of exertion if based solely on HR.

Squash 1.0-1.1

Squash is similar to badminton by nature, yet a lower factor is recommended because the movements are shorter than in badminton.

Soccer 1.0

See tennis. The demands of soccer depend greatly on the player's role.

Skating 1.1-1.2

In line skating resembles cycling but the resting periods are longer (step frequency is very low). On the other hand, there is a long static phase during each step which makes the sport rather heavy.

Cross-country skiing: classic 0.9

It is possible to reach the same HR somewhat easier in whole-body work, but also the total energy expenditure will be a little more on a given HR than in running.

Cross-country skiing: freestyle 1.1-1.2

Skating or freestyle skiing very much resembles skating, yet the HR is lower than in the classic style mainly because of long static phases and relatively slow movements and frequency in the upper body.

These examples refer only to normal conditions, and are not applicable to extremely long or exhaustive exercise sessions. These factors are valid only together with HR data. It cannot be stated that 1 hour of biking is 10% harder than 1 hour running. The question should rather be put in this way: “Is it harder to run at HR of 150 beats/min than to cycle at the same HR?”.

4.1.2 The algorithm

Using the aforesaid formula and method, the exertion algorithm has been implemented. Its functioning is very simple: for each existing HR interval, it multiplies the related exertion factor (chosen with relation to the figure 4.4) per time spent in that HR interval. Then, the algorithm sums all these values and applies the related sport factor.

Finally, it is important to notice that, if there is more than one training session in a day, the algorithm calculates the daily exertion count as sum of all the exertion counts of each training session.

The implemented exertion algorithm is described in detail by the following pseudo-code:

1 **initialize** total exertion value of a log at 0

2 **execute cycle** for all logs of a single day

- **2.1** **initialize** partial HR interval exertion at 0
- **2.2** **execute cycle** for all athlete's HR intervals
  - **2.2.1** retrieve seconds, minutes and hours spent in this HR interval
  - **2.2.2** **transform all in minutes:** multiply hours spent per 60
  - **2.2.3** transform all in minutes: divide seconds spent per 60
  - **2.2.4** sum of transformed seconds and transformed hours and minutes
  - **2.2.5** multiply total time spent per related exertion factor
  - **2.2.6** add the calculated partial HR interval exertion (i) to the previous one (i-1)
- **2.3** multiply the total exertion value of a log per the related sport factor
- **2.4** add the calculated total exertion value of a log (i) to the previous one (i-1)

4.2 Gradient algorithm

It is very important to know the athlete's performance respect to the altitude development of a track. In fact, athletes could have significant difference in terms of speed or energy consumption depending on the ground slope. For example, an athlete could have a great resistance in a climb, but not have a good running technique during slopes, so his/her performances can be affected by these factors. Studying track profiles related on training session is useful to highlight body limits or athletic faults, to perform the best training sessions to improve athletes performances.

Starting from the punctual values of distance and altitude, represented on the x-axis and y-axis of a Cartesian graph respectively, this algorithm has the goal to show a different track profile. It associates to a single line segment more sub-segments which have in common the similar gradient value. This is important to obtain a less jagged track profile, which can be studied and analyzed with much more simplicity. From it, one can see lots

of information about track gradient in different parts of the track, like for example HR, speed and energy consumption variation in relation with their own gradient values.

The gradient algorithm utilizes the line segment interpolation to calculate in a easy way the gradient value. Obviously exist lots of algorithms to interpolate points, but the undersigned uses the line segment because:

- it is the simplest one;
- it does not introduce noise in calculation;
- it is not possible to know the exact track profile between two points, so it is impossible to establish which algorithm is the best one;
- modifying the angular limit, it is possible to obtain many precision levels.

The algorithm idea is that a point belongs to a certain line segment, if the gradient of the segment line delimited by the same point and the previous one, respect to the average gradient value of the line segment, does not exceed a calculated threshold (expressed in terms of decimal degrees). This is the basic idea of the gradient algorithm, that functions very well if the track has steep climbs or large slopes, exactly as shown in the following picture:

Figure 4.5. Climbs and slopes

The decision threshold allows that there will be a little angular margin between two different gradient values, both in slope and in climb. For this reason, it is possible to obtain profiles like the following one:

Figure 4.6. Gradient view

Moreover, a last consideration has to be made. In reality, lots of tracks have a different profile in terms of altitude. For example, mountain roads, with lot of ups and downs can be easily imagined. For this reason, the original idea has been improved: not only one point has been involved in the calculation, but also its two following points. This improvement is useful because the algorithm does not only consider one point respect to the line segment gradient, but also the future progression of the track profile. In this way it is possible to avoid and to do not consider little oscillations of the profile or wrong altitude values. The following picture is an example of this behavior:

Figure 4.7. Possible wrong value

It is necessary now to describe how the algorithm works, scanning each point of the track profile. It involves in its calculation four points at a time: the current scanned point, the previous point and the two following ones. It starts calculating the fictitious gradient value of the three different line segments delimited by the mentioned points:

- the first is delimited by the current point and the previous one;
- the second is delimited by the next point of the current point and the previous one;
- the third is delimited by the second next point and the previous one.

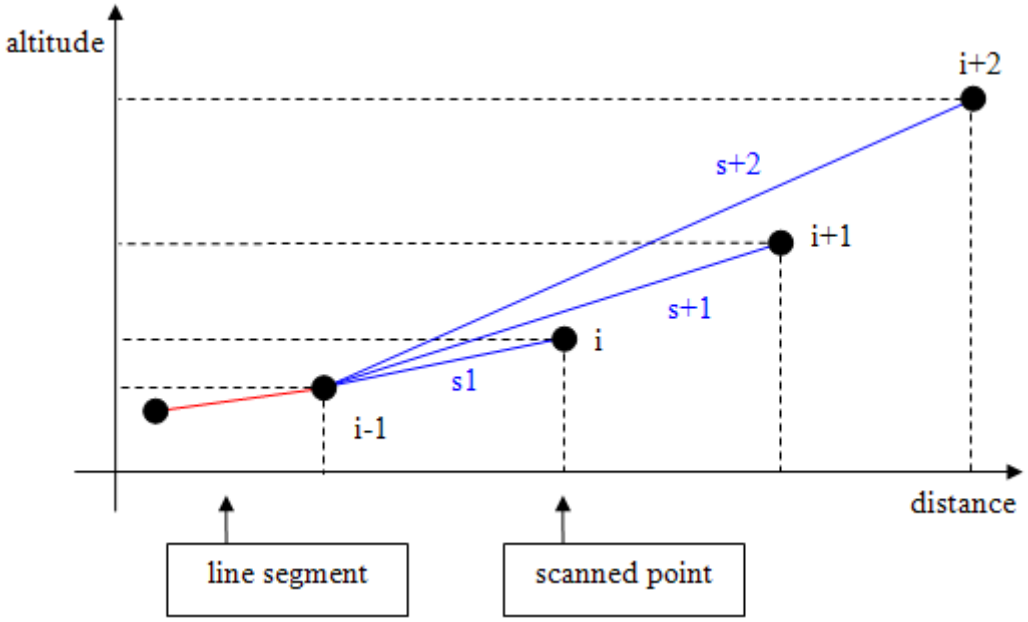


Figure 4.8. Involved points in gradient algorithm

In the picture, the scanned point is marked as “i”, the previous point “i-1” and the following ones “i+1” and “i+2”. Intuitively, the line segments’ names are “s1”, “s+1” and “s+2” respectively. Furthermore, it is important to state that in the gradient calculation, the distance between two points has been intended as horizontal distance and not as inclined one. Since the majority of distance data are originated by GPS devices, the undersigned has utilized the topographic approach that works in this way. In addition, the difference between the two distances is so little that can be assumed as nonessential, and the precision of the calculation is not affected by errors. The gradient is expressed by the α angle of a right-angled triangle, as shown:

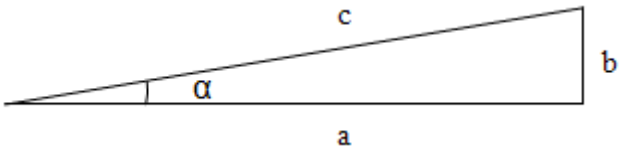


Figure 4.9. Right-angled triangle

Using the trigonometry law, the formula for α angle is the following:

$$\alpha = \left[\arctan\left(\frac{b}{a}\right)\right] \tag{4.2}$$

And it follows that the formula for gradient is:

$$\alpha^{rad} = \left[\arctan\left(\frac{altitude}{distance}\right)\right] \tag{4.3}$$

The C++ programming language offers a library to developers, **math.h**, which contains lot of mathematics functions [2]. The formula for gradient which has been used in this project, has been lightly modified because **math.h** can only manage radiant angles, but to be more user-friendly, the +Atleta interface show only decimal degrees. The final formula for gradient calculation is:

$$\alpha^{\circ} = \left[\arctan\left(\frac{altitude}{distance}\right)\right] \cdot \frac{180}{\pi} \tag{4.4}$$

Once the three fictitious gradient values are calculated, the algorithm updates the value of the current general line segment gradient. It is calculated as average of all the sub-line segment gradients, which are composing (at the moment) the questioned line segment. The algorithm operates a comparison between it and the evaluated fictitious gradients calculated in advance. This comparison establishes if the current point (i) could be part of

the current line segment. The “i+1” and “i+2” points represent the future development of the track, and for this reason assume a great importance in this decision. They can avoid errors due to little track oscillations or wrong stored altitude values. It is also important to notice that an angular threshold exists (defined and configured by users) to perform this comparison. The “i” point belong to the line segment if one of the following conditions is satisfied:

- if gradient of “s1” does not exceed the angular threshold;
- if gradient of “s2” does not exceed the angular threshold;
- if gradient of “s3” does not exceed the angular threshold.

Observing this rule, it is easy to notice that “i” point does not belong to the line segment only in the case that all three fictitious gradients exceed the angular threshold. For this reason, different scenarios could be presented:

1. current point belong to the line segment because “i” point does not exceed the angular threshold

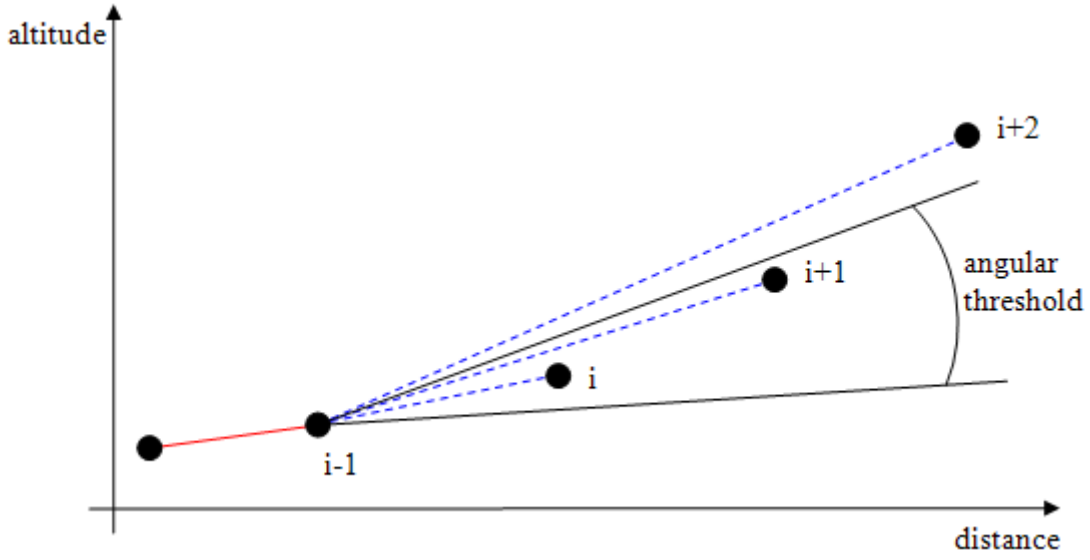


Figure 4.10. Case 1

2. current point belong to the line segment because “i+1” point does not exceed the angular threshold. In this case “i” altitude exceed the angular threshold, but the algorithm considers more important the future track trend. This altitude is rejected: it can be considered as a wrong value which is due to device errors. Here an example:

Figure 4.11. Case 2, graph view

The shown graph could be represented in this way:

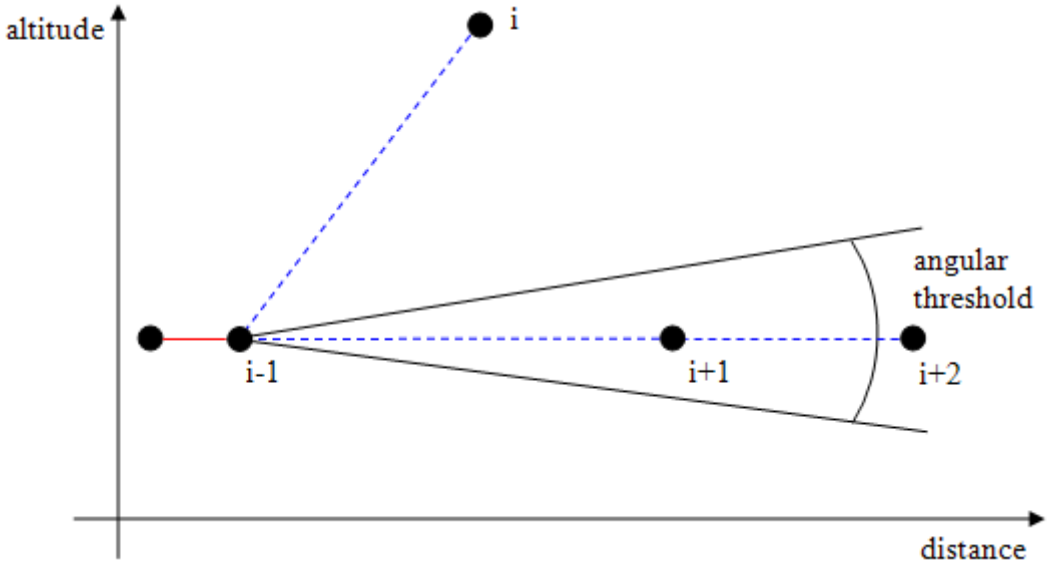


Figure 4.12. Case 2, schematic view

3. current point belong to the line segment because “i+2” point does not exceed the angular threshold. This case is similar to the previous one, but there are two values that are out of scope. Next picture will show an example.

Figure 4.13. Case 3, graph view

The shown graph could be represented in this way:

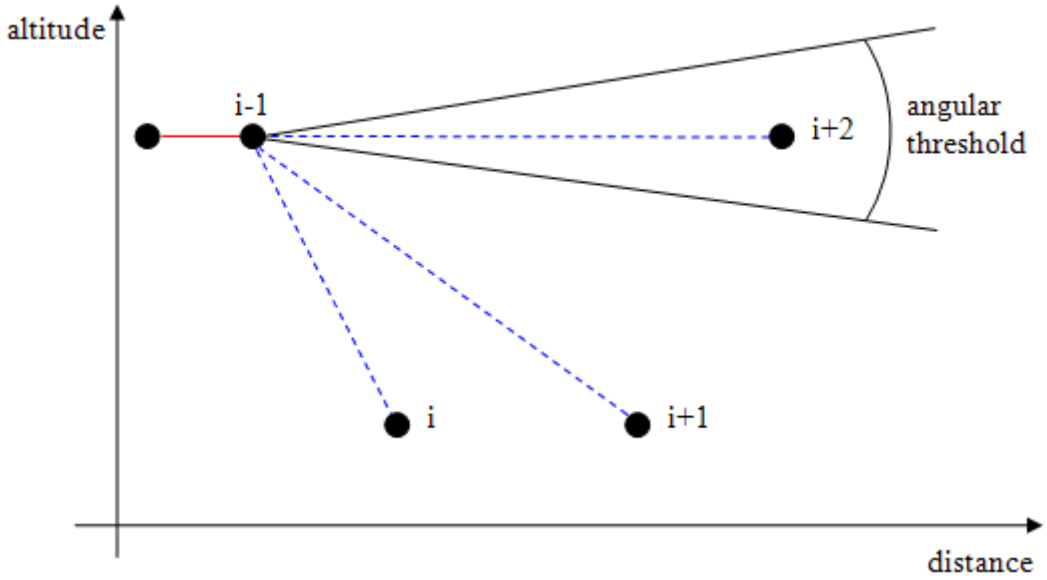


Figure 4.14. Case 3, schematic view

4.2.1 The algorithm

In order to summarize what has been described until now, it can be said that the algorithm works in the following way: before deciding if a point could be part of a certain line segment, three tests are performed. They check if all the three next points (of the point considered in a certain moment) could be part of the line segment. This happens comparing the average gradient of the general line segment and the three gradients of the line segments, i.e. segments obtained joining the points "i", "i+1" and "i+2" with the point "i-1". It is necessary that at least one of the three tests is past, to consider the "i" point as part of the general line segment. In this way, all points belonging to the track are checked, not simply testing their positions, but also keeping the future track trend into account.

The detailed gradient algorithm is described by the following pseudo-code:

1 execute cycle from 1st element to third last element of punctualData vector

- **1.1 if** previous point (i-1) is the starting point of the track
  - **1.1.1 calculate the gradient** of the segment delimited by it (i-1) and current point (i)
- **1.2 else** segment's gradient value already exists
  - **1.2.1 update** it calculating new average segment's gradient (*segmentGradient*)
- **1.3** retrieve relative distance and relative altitude between current point (i) and previous point (i-1)
- **1.4 calculate gradient** of the segment delimited by current point (i) and previous point (i-1)
- **1.5** retrieve relative distance and relative altitude between next point (i+1) and previous point (i-1)
- **1.6 calculate gradient** of the segment delimited by next point (i+1) and previous point (i-1)
- **1.7** retrieve relative distance and relative altitude between second point (i+2) and previous point (i-1)

1.8 calculate gradient of the segment delimited by second next point (i+2) and previous point (i-1)

1.9 calculate tolerance range, the maximum (*maxRange*) and minimum (*minRange*) angular limit as sum/subtraction of *segmentGradient* and *gradientFactor*

1.10 perform a three level tolerance control: if gradient calculated at (1.4) exceeds the tolerance range

1.10.1 if gradient calculated at (1.6) exceeds the tolerance range

1.10.1.1 if gradient calculated at (1.8) exceeds the tolerance range

1.10.1.1.1 current point is not part of previous line segment because it is out of range

1.10.1.1.2 store data related to previous line segment. It goes from starting point to (i-1) point

1.10.1.1.3 set previous point as the new starting point

1.11 return at the cycle start (1)

2 update mean segment's gradient (*segmentGradient*)

3 retrieve relative distance and relative altitude between current point (i) and previous point (i-1)

4 calculate gradient of the segment delimited by current point (i) and previous point (i-1)

5 retrieve relative distance and relative altitude between next point (i+1) and previous point (i-1)

6 calculate gradient of the segment delimited by next point (i+1) and previous point (i-1)

7 calculate tolerance range, the maximum (*maxRange*) and minimum (*minRange*) angular limit as sum/subtraction of *segmentGradient* and *gradientFactor*

8 perform a two level tolerance control: if gradient calculated at (4) exceeds the tolerance range

8.1 if gradient calculated at (6) exceeds the tolerance range

8.1.1 current point is not part of previous line segment because it is out of range

8.1.2 store data related to previous line segment. It goes from starting point to (i-1) point

8.1.3 set previous point as the new starting point

9 update mean segment's gradient (*segmentGradient*)

10 retrieve relative distance and relative altitude between current point (i) and previous point (i-1)

11 calculate gradient of the segment delimited by current point (i) and previous point (i-1)

12 calculate tolerance range, the maximum (*maxRange*) and minimum (*minRange*) angular limit as sum/subtraction of *segmentGradient* and *gradientFactor*

13 perform a single level tolerance control: if gradient calculated at (11) exceeds the tolerance range

13.1 last track point (current point) is not part of previous line segment because it is out of range

13.2 store data related to previous line segment. It goes from starting point to (i-1) point

13.3 set previous point as the new starting point

13.4 store data related to the last line segment. It goes from previous point (i-1) point to current and last track point

14 else last track point (current point) is part of previous line segment (last track line segment)

14.1 store data related to last line segment. It goes from starting point to the track final point

4.3 Bend algorithm

Starting from the simple topographic coordinates, this algorithm has the purpose to detect when there is a bend in the track and if it is a left bend or a right one. It is important to know these circumstances because each runner has his own run technique that very much depends on his preferred leg, i.e. a leg more powerful than another. The fact that each athlete has got a preferred leg, could entail differences in term of speed and energy consumption and could concern a left or a right bend. For this reason, to cover a track in a way or in the opposite one, could involve that the same athlete can obtain different performances. This behaviour has been acutely taken into consideration, studied and analyzed.

The idea of this algorithm is that a track is represented by a sequence of line segment. Track data are GPS coordinates which can be displayed by using a simple Cartesian graph. Depending on the amplitude of the calculated angle between each adjacent line segment, the following cases can be presented:

- if the angle value is too high, compared to a fixed threshold, there is no bend. The reason is that the two line segment compose nearly a straight line;
- if the angle is under the threshold there are different scenarios:
  - there is a bend if the previous bend is too far (respect to the fixed "distance threshold") or if the previous one is on the opposite side;
  - there is not a new bend, because this one is already part of a greater bend.

Therefore, this algorithm establishes these different scenarios and it detects in which one the analyzed line segment is in. Then, it stores parameters like mean HR, speed, energy consumption and gradient of each bends. It is important to notice that, if a bend is composed by more than two line segments, the algorithm provides for the average calculation of the aforesaid parameters. Moreover, it does an average among all the line segments involved.

The first step consists on a transformation of a line segment, expressed by the Cartesian coordinates of its extreme points, into a line segment expressed by polar coordinates. Polar coordinates are the length (s) and the angle (α).

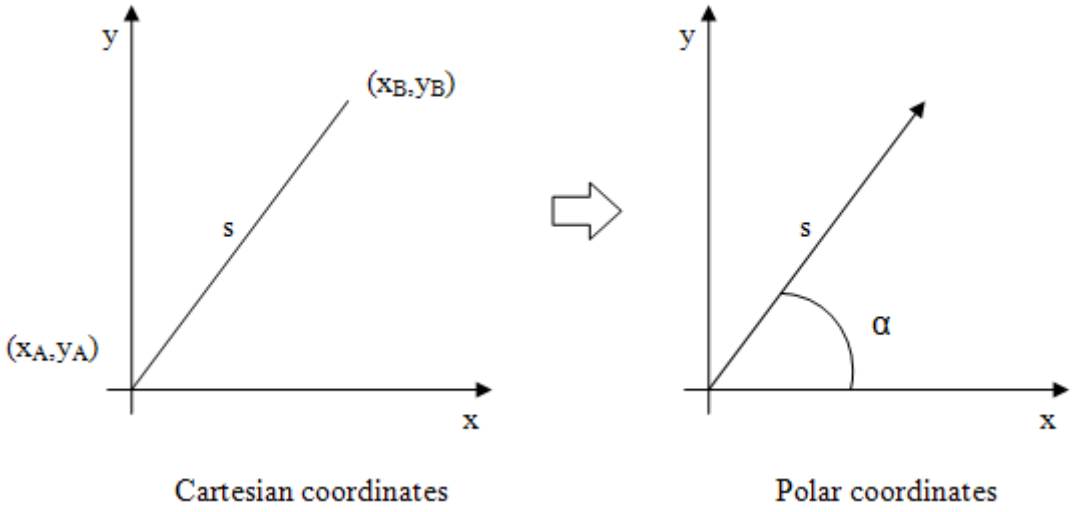


Figure 4.15. Point's representations

In order to do this, it is useful to apply the Pythagorean theorem, and to calculate the "s" line segment as the hypotenuse of a right-angled triangle. It is shown by the following picture:

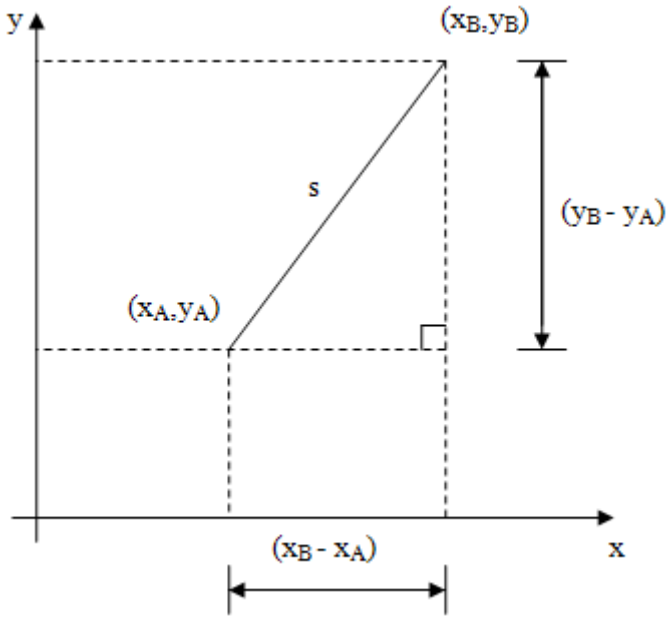


Figure 4.16. Right-angled triangle

The formula is:

$$s = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \tag{4.5}$$

The fundamental aspect to continue in the bend calculation is to obtain the polar length of each adjacent line segments. The following step is to calculate the angle between them. To reach this goal it is necessary to use Carnot's theorem. It states the following relations between sides and angles and could be applied to any triangle:

$$a^2 = b^2 + c^2 - 2 \cdot b \cdot c \cdot \cos\alpha \tag{4.6}$$

$$b^2 = a^2 + c^2 - 2 \cdot a \cdot c \cdot \cos\beta \tag{4.7}$$

$$c^2 = b^2 + a^2 - 2 \cdot b \cdot a \cdot \cos\gamma \tag{4.8}$$

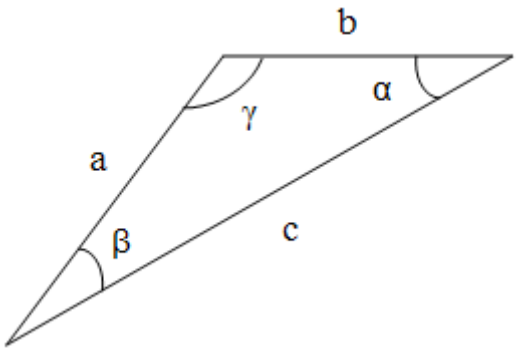


Figure 4.17. Carnot's triangle

In the case of a track, considering two line segment at a time, the triangle could appear in this form:

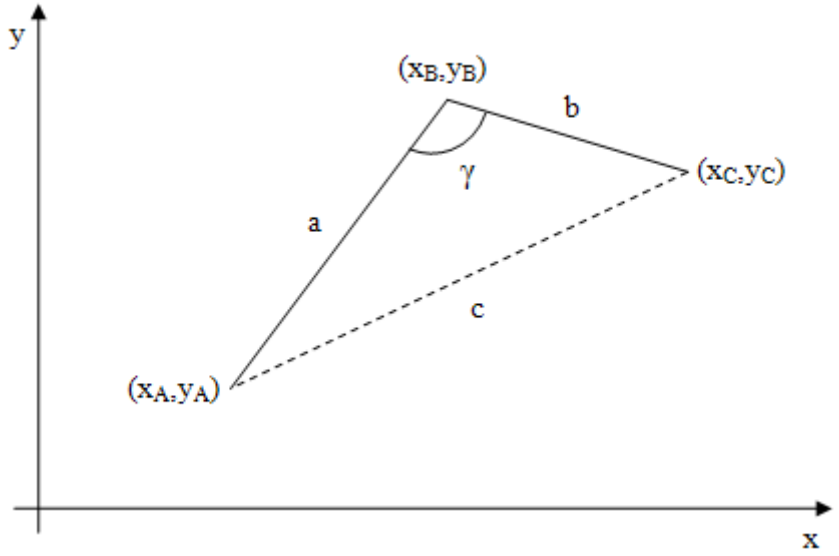


Figure 4.18. Bend angle

Moreover, once the sides of the triangle have been calculated with the 4.5 formula (as shown in the picture, they are the real line segments "a" and "b" and the fictitious one

"c"), with the inversion of the formula 4.8, it is easy to find the γ angle, i.e. the bend angle:

$$\gamma = \arccos\left(\frac{b^2 + a^2 - c^2}{2 \cdot a \cdot b}\right) \tag{4.9}$$

The next step is more complicated. It has the goal to determine if the bend is on the right or on the left side. In order to do this, it is necessary operate a roto-translation of the Cartesian axis. This operation has to be done for each bend and is the way to determine the following bend's side. Particularly, the x-axis is superimposed to the analyzed line segment and its direction is the same of the track's one. The following example will better clarify this concept:

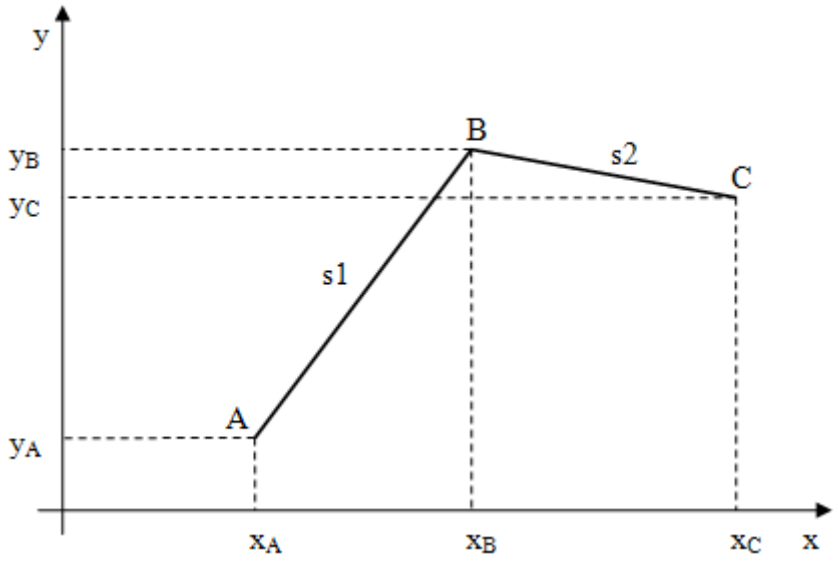


Figure 4.19. Axis' standard configuration

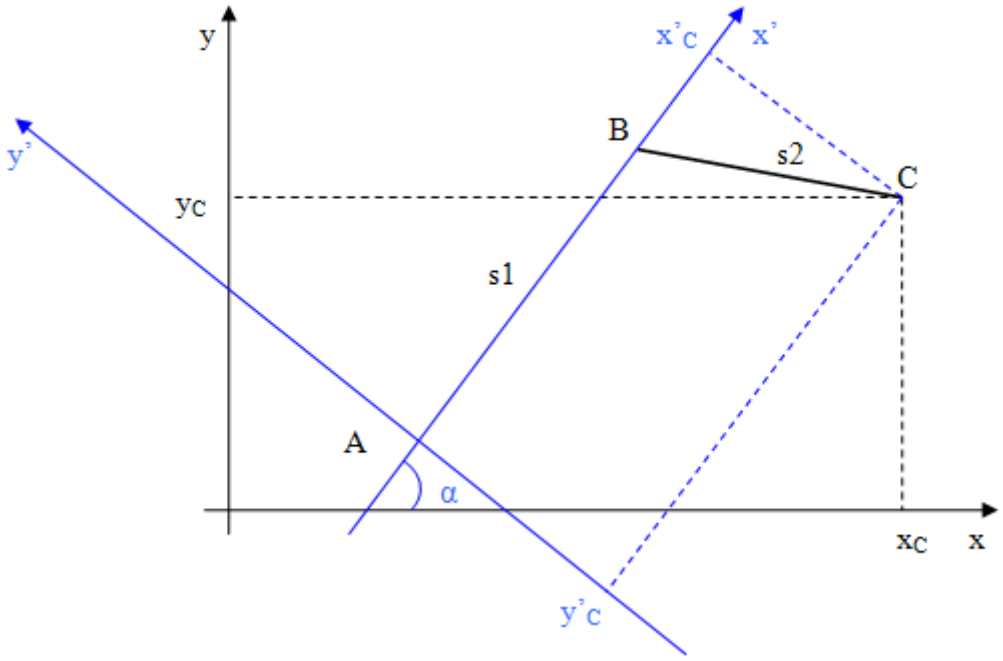


Figure 4.20. Axes' roto-translation

With this new axis's configuration, the new axis origin is represented by point "A" and x-axis is superimposed to the first line segment "s1". In this way, the only coordinates that have to be estimated are related to point "C". In order to calculate them, it is necessary to use the following formulas:

$$x_C^{'} = (x_C - x_A) \cdot \cos\alpha + (y_C - y_A) \cdot \sin\alpha \tag{4.10}$$

$$y_C^{'} = -(x_C - x_A) \cdot \sin\alpha + (y_C - y_A) \cdot \cos\alpha \tag{4.11}$$

Once the roto-translation has been performed and one knows the new relative coordinates of "C" point (x'_C ,y'_C), the bend's side is easy to determine:

left if $y'_C > 0$
right if $y'_C < 0$

The last point that has to be analyzed is bend sequence. In fact, different configurations and scenarios will be developed:

- different bends with different sides: the software analyses the points; it also detects that there are two different bends, even if the points "B" and "C" would be under the distance threshold.

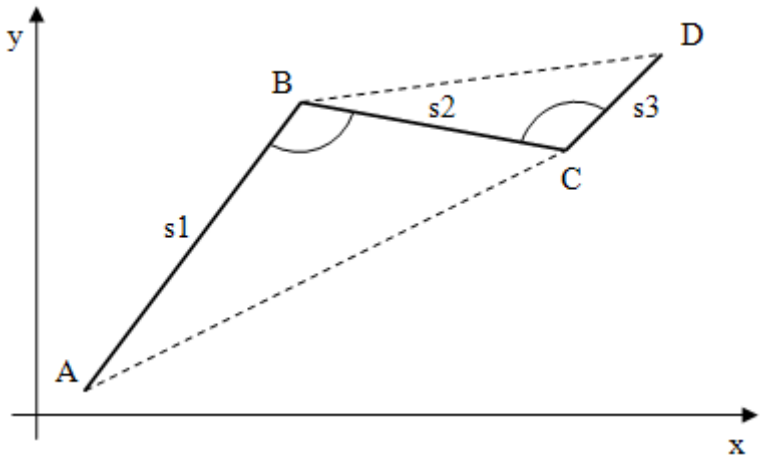


Figure 4.21. Different bends with different sides

- Different bends on the same side: the algorithm analyses the points and detects that there are two different bends on the same side. This is due to the fact that the distance between them is too large, in comparison with fixed distance threshold.

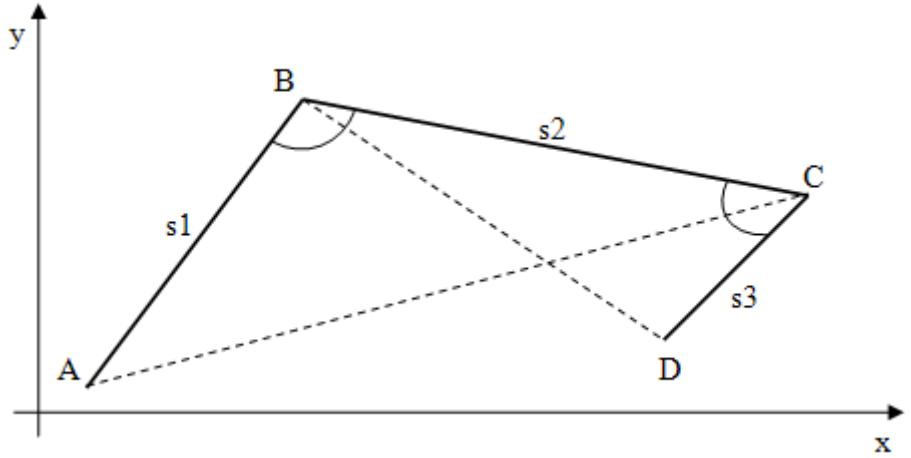


Figure 4.22. Different bends on the same side

- Different bends on the same side that compose a single bend: the algorithm analyses the points and detects that there is only a bend, composed by more than two line segments. This is due to the fact that they are on the same side and the distance between them is too small compared with the fixed distance threshold. In this particular case, all parameters estimated like angle, altitude, distance, HR, speed, energy consumption and gradient will be calculated as the mean value of all parameters of each line segment involved in the calculation.

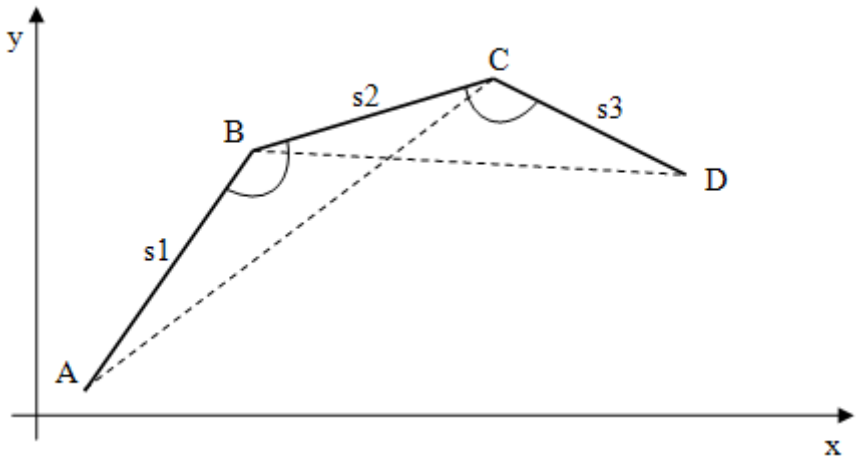


Figure 4.23. Composed bend

Furthermore, it is important to state that in the gradient calculation, as well as exposed in the previous paragraph (Gradient algorithm 4.2), the distance between two points has been intended as horizontal distance and not as inclined one. The gradient is so expressed by the α angle of a right-angled triangle, as here shown:

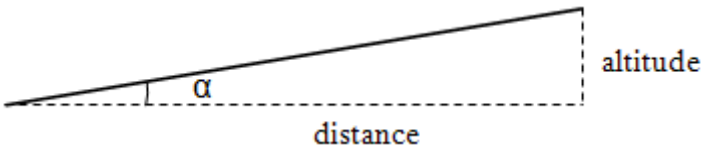


Figure 4.24. Gradient

Using the trigonometry laws, the formula for α angle is the following:

$$\alpha^{\circ} = \left[\arctan\left(\frac{altitude}{distance}\right)\right] \cdot \frac{180}{\pi} \tag{4.12}$$

4.3.1 The algorithm

As a summary of what has been said until now, the algorithm works in the following way: initially Polar coordinates are calculated to transform points represented by Cartesian coordinates into more useful line segments. For each couple of adjacent line segments, an axes' roto-translation is performed to align the x-axis with the line segment at issue. This operation is essential to understand, depending on the position of the line segments, if there is a left or a right bend. The algorithm provides for the cases in which bends are composed by more segments or there is not a bend, if the set angular limit is not exceeded.

Finally, the detailed implemented bend algorithm is described by the following pseudo-code:

1 execute cycle from 1st element to third last element

- **1.1 apply Pythagorean theorem** to calculate polar distance between current point (i) and second point (i+1) -> this line segment is called "a"
- **1.2 apply Pythagorean theorem** to calculate polar distance between second point (i+1) and third point (i+2) -> this line segment is called "b"
- **1.3 apply Pythagorean theorem** to calculate polar distance between current point (i) and third point (i+2) -> this line segment is called "c"
- **1.4 apply Carnot's theorem** to calculate the angle between first and second segment line -> this angle is called "gamma"
- **1.5** add "a" to the variable "cumulativeDistance"
- **1.6 if** "a" belong to the first quadrant
  - **1.6.1 set** variable "addToAngle" to 0

1.7 if "a" belong to the second quadrant

1.7.1 set variable "addToAngle" to $3\pi/2$

1.8 if "a" belong to the third quadrant

1.8.1 set variable "addToAngle" to π

1.9 if "a" belong to the fourth quadrant

1.9.1 set variable "addToAngle" to $\pi/2$

1.10 if "a" is parallel to the x-axis

1.10.1 if "a" goes from left to right

1.10.1.1 set variable "addToAngle" to 0

1.10.2 if "a" goes from right to left

1.10.2.1 set variable "addToAngle" to $3\pi/2$

1.11 if "a" is parallel to the y-axis

1.11.1 if "a" goes from up to down

1.11.1.1 set variable "addToAngle" to π

1.11.2 if "a" goes from down to up

1.11.2.1 set variable "addToAngle" to 0

1.12 if "gamma" is under the threshold, there is a bend

1.12.1 calculate "a" and "b" **gradient values**

1.12.2 calculate rotation axis angle to perform the axes roto-translation -> this angle is called "rotationAngle"

1.12.3 if "rotationAngle" is <0

1.12.3.1 "rotationAngle"="angleToAdd" + $\pi/2$ + "rotationAngle"

1.12.4 else

1.12.4.1 "rotationAngle"="angleToAdd" + "rotationAngle"

1.12.5 calculate third point's Y coordinate, respect to the new axis inclination -> this variable is called "relativeThirdPointY"

1.12.6 if "relativeThirdPointY" > 0, there is a LEFT bend

1.12.6.1 if this is the continuation of the previous bend

1.12.6.1.1 save parameters and update data

1.12.6.2 if there is a different bend on the same side as the previous one

1.12.6.2.1 store previous bend

1.12.6.2.2 save parameters and update data

1.12.6.3 if there is a different bend on the other side respect to the previous one

1.12.6.3.1 store previous bend

1.12.6.3.2 save parameters and update data

1.12.7 else, there is a RIGHT bend

1.12.7.1 if this is the continuation of the previous bend

1.12.7.1.1 save parameters and update data

1.12.7.2 if there is a different bend on the same side as the previous one

1.12.7.2.1 store previous bend

1.12.7.2.2 save parameters and update data

1.12.7.3 if there is a different bend on the other side respect to the previous one

1.12.7.3.1 store previous bend

1.12.7.3.2 save parameters and update data

1.13 return at the cycle start (1)

Chapter 5

Implementation

This chapter is the consequence of the objectives, project guidelines and requirements explained in previous chapters. The whole implemented system's architecture, all components and classes will be described in detail. In order to exhaustively explain the implemented code, this chapter is divided into five sections, each one referred to a particular aspect of the system's implementation.

5.1 Use cases

Use cases identify system's features and associate them with the related actors. As can be seen from the picture in the next page, the human actor could be only Athlete (*Atleta*) or Trainer (*Entrenador*). The other actor involved in the described operation is clearly the system. Each use case describes the existing relations between actors and specify actions done by them.

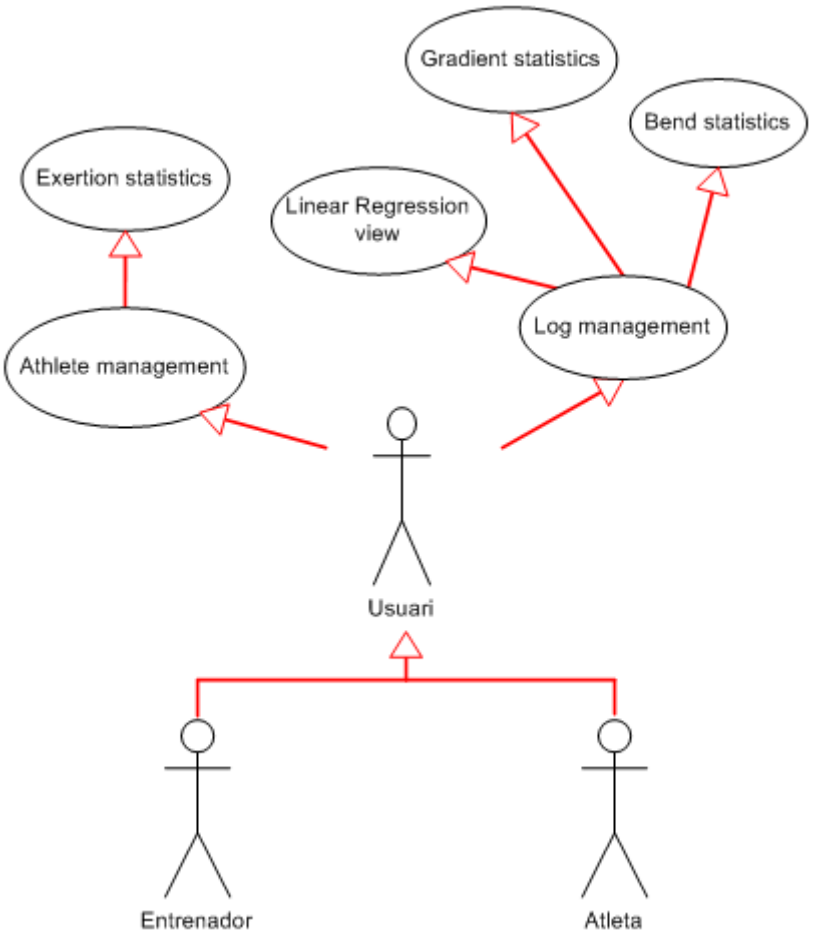


Figure 5.1. General use cases

5.1.1 Log management

Use case: linear regression view

Actors: user, system

Summary: to view the linear regression graph of the selected parameters

USER	SYSTEM
1. User selects the preferred linear regression of a particular log, choosing from a list.	
	2. It checks the correctness of the data to process. 3. System establishes a connection with R and shows the linear regression graph, the textual output and the descriptive statistics of the two parameters involved.
4. User can select the reverse view.	
	5. It checks the correctness of the data to process. 6. System shows the reverse view and the same statistics described at the step nr. 3.

Exceptions:

- Step 2: the system detects an error and shows a warning message box.
- Step 5: the system detects an error and shows a warning message box.

Use case: gradient statistics

Actors: user, system

Summary: to view the gradient statistics of the selected log

USER	SYSTEM
1. User selects the gradient statistic view.	
	2. It checks the correctness of the data to process. 3. System performs the *gradient algorithm*, shows the track profile and the related statistics.
4. User can set up the *gradient factor* value.	
	5. It checks the correctness of the filled data value. 6. System performs again the *gradient algorithm*, shows the track profile and the related statistics.
7. User can set up the *gradient factor* value as default value.	
	8. System performs again the *gradient algorithm*, shows the track profile and the related statistics.
9. He/she can select the detailed gradient view.	
	10. It shows the detailed gradient statistics and the track profiles.
11. Used can select the preferred linear regression view choosing from different buttons.	
	12. It checks the correctness of the data to process. 13. System establishes a connection with R and shows the linear regression graph, the textual output and the descriptive statistics of the two parameters involved.

Exceptions:

- Step 2: the system detects an error and shows a warning message box.
- Step 5: the system checks if the filled value is too low or too high and asks user confirmation by showing a warning message box.
- Step 12: the system detects an error and shows a warning message box.

Use case: bend statistics

Actors: user, system

Summary: to view the bend statistics of the selected log

USER	SYSTEM
1. User selects the bend statistic view.	
	2. It checks the correctness of the data to process. 3. System performs the *bend algorithm*, shows the track profile and the related statistics.
4. User can set up the *angular limit* and the *length limit* values.	
	5. It checks the correctness of the filled data values. 6. System performs again the *bend algorithm*, shows the track profile and the related statistics.
7. User can set up the *angular limit* and the *length limit* values as default values.	
	8. System performs again the *bend algorithm*, shows the track profile and the related statistics.
9. He/she can select the detailed bend statistics view.	
	10. It shows the detailed bend statistics and the track profile.
11. Used can select the preferred linear regression view choosing from different buttons.	
	12. It checks the correctness of the data to process. 13. System establishes a connection with R and shows the linear regression graph, the textual output and the descriptive statistics of the two parameters involved.

Exceptions:

- Step 2: the system detects an error and shows a warning message box.
- Step 5: the system checks if the filled values are too low or too high and asks user confirmation by showing a warning message box.
- Step 12: the system detects an error and shows a warning message box.

5.1.2 Athlete management

Use case: exertion statistics

Actors: user, system

Summary: to view the exertion statistics of the selected athlete

USER	SYSTEM
1. User selects the exertion statistic view.	
	2. System performs the *exertion algorithm*, shows the monthly exertion view and the related statistics.
3. User can set up the *exertion coefficients* values.	
	4. It checks the correctness of the filled data values. 5. System performs again the *exertion algorithm*, shows the track profile and the related statistics.
6. User can set up the *exertion coefficients* as default values.	
	7. System performs again the *exertion algorithm*, shows the track profile and the related statistics.
8. User can set up the *sport factor* value.	
	9. It checks the correctness of the filled data value. 10. System performs again the *exertion algorithm*, shows the track profile and the related statistics.
11. User can set up the *sport factor* as default value.	
	12. System performs again the *exertion algorithm*, shows the track profile and the related statistics.
13. User can choose the previous month view.	
	14. System displays the previous month statistics.
15. User can reset the month view.	
	16. System displays the current month statistics.
17. Used can select the preferred linear regression view choosing from different buttons.	
	18. It checks the correctness of the data to process. 19. System establishes a connection with R and shows the linear regression graph, the textual output and the descriptive statistics of the two parameters involved.
20. User can choose the *week view*.	
	21. System displays the *weekly view* panel.

Exceptions:

- Step 4: the system checks if the filled values are too low or too high and asks user confirmation by showing a warning message box.

- Step 9: the system checks if the filled value is too low or too high and asks user confirmation by showing a warning message box.
- Step 18: the system detects an error and shows a warning message box.
- Step 21: the system shows the weekly view panel, which has the same statistics and contents of the monthly view panel; the only difference is that the time division is week-based.

5.2 Conceptual model

Conceptual model shows implemented classes and relations between them. In this paragraph four UML diagrams are presents; each one is related to a particular area of interest: linear regression, exertion algorithm, gradient algorithm or bend algorithm.

5.2.1 Linear regression classes

The involved classes to perform a linear regression are:

- treeTestView;
- queryManager;
- gestorDisc;
- CdialogManager classes.

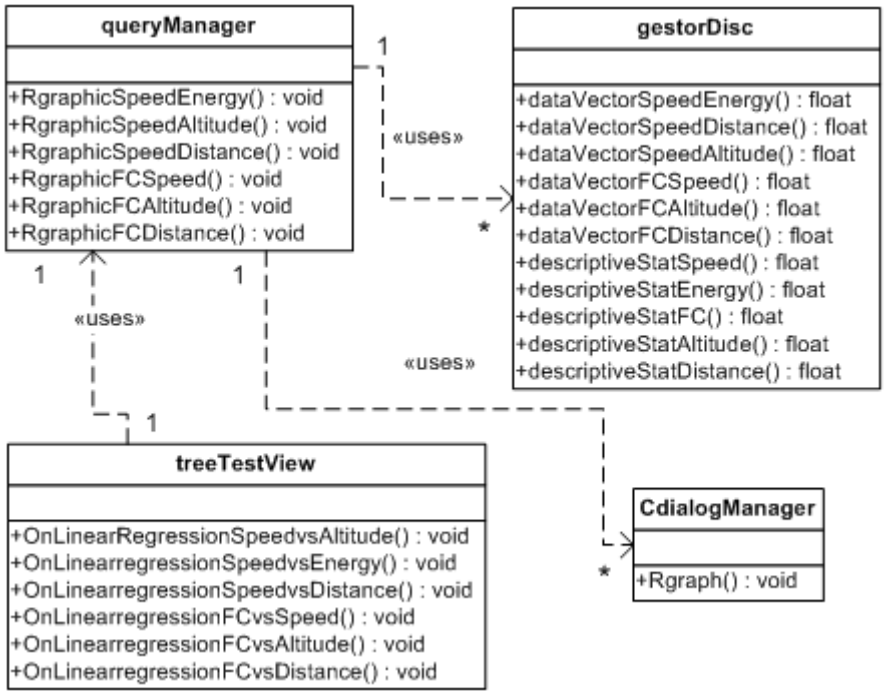


Figure 5.2. UML diagram for linear regression

treeTestView class

Depending on the user's choice, each menu's voice activates a different *queryManager* method. More in detail, each method retrieves from the system the athlete's name and the identifier of the select log; it passes this parameters to the related method of *queryManager* class.

The menu that allows the user to choose the preferred linear regression is present in the next page.

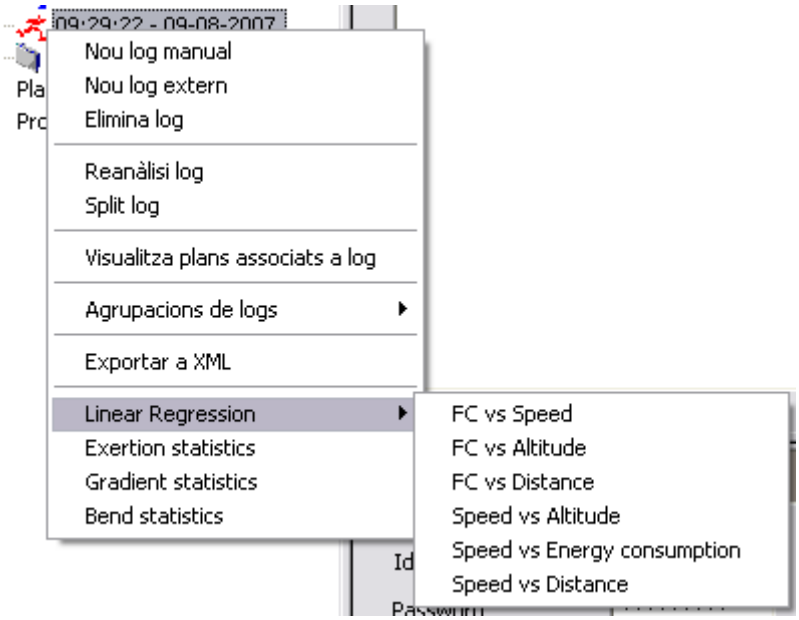


Figure 5.3. Linear regression menu

queryManager class

This class receives two parameters from *treeTestView*, the athlete's name and the log identifier; subsequently it performs calls to the lower level, where *gestorDisc* works. Its function is to receive parameters to display, that will be past to the graphic class. Each of the following methods retrieve a different couple of vector (for example FC and Speed), depending on the previous user's choice. Furthermore, it retrieves from *gestorDisc* average, maximum and minimum values of the two parameters. The most important implemented methods are:

```
void RgraphicSpeedEnergy(string idLog,string idUsuari)
```

It retrieves punctual values of speed and energy consumption of the selected log and the descriptive statistics like average, minimum and maximum values.

```
void RgraphicSpeedAltitude(string idLog,string idUsuari)
```

It retrieves punctual values of speed and altitude of the selected log and the descriptive statistics.

`void RgraphicSpeedDistance(string idLog,string idUsuari)`

It retrieves punctual values of speed and distance of the selected log and the descriptive statistics.

`void RgraphicFCSpeed(string idLog,string idUsuari)`

It retrieves punctual values HR and speed of the selected log and the descriptive statistics.

`void RgraphicFCAltitude(string idLog,string idUsuari)`

It retrieves punctual values HR and altitude of the selected log and the descriptive statistics.

`void RgraphicFCDistance(string idLog,string idUsuari)`

It retrieves punctual values HR and distance of the selected log and the descriptive statistics.

gestorDisc class

It represents the lower point of the software, because it is the closer to the database level. Its main function is to interrogate the database. To do this, *gestorDisc* uses mySQL++ library class and gives the retrieved data (which are stored in a vector) to the *queryManager*. They could be descriptive statistics or punctual parameters values. The most important implemented methods are:

`dataVectorSpeedEnergy (string idLog, string idU)`

It returns punctual values of speed and energy consumption of a log.

`dataVectorSpeedDistance (string idLog, string idU)`

It returns punctual values of speed and distance of a log.

`dataVectorSpeedAltitude (string idLog, string idU)`

It returns punctual values of speed and altitude of a log.

`dataVectorFCSpeed (string idLog, string idU)`

It returns punctual values of HR and speed of a log.

`dataVectorFCAltitude (string idLog, string idU)`

It returns punctual values of HR and altitude of a log.

`dataVectorFCDistance (string idLog, string idU)`

It returns punctual values of HR and distance of a log.

About descriptive statistics, these are the implemented methods:

`vector<float> descriptiveStatSpeed (string idLog, string idU)`

Speed average, maximum and minimum values.

`vector<float> descriptiveStatEnergy (string idLog, string idU)`

Energy consumption average, maximum and minimum values.

`vector<float> descriptiveStatFC (string idLog, string idU)`

HR average, maximum and minimum values.

`vector<float> descriptiveStatAltitude (string idLog, string idU)`

Altitude average, maximum and minimum values.

`vector<float> descriptiveStatDistance (string idLog, string idU)`

Distance average, maximum and minimum values.

CdialogManager classes

Following classes belong to this category:

- RgraphSpeedEnergy;
- RgraphSpeedDistance;
- RgraphSpeedAltitude;
- RgraphFCSpeed;
- RgraphFCAltitude;
- RgraphFCDistance.

They implement a linear regression view, using the COM/DCOM object described in the paragraph 3. Each class shows a couple of different variables, but their code structure and functioning is the same. For this reason it is possible to concentrate the attention only on one of them, for example, *RgraphSpeedEnergy* class. Its function is essentially

to receive parameters from *queryManager* and to perform the linear regression using R. In particular, it receives the vectors of Speed and Energy consumption punctual values, and the vectors of the related descriptive statistics (it means maximum, minimum and average values). Subsequently, it transforms this vectors into `CcomSafeArray` arrays [3]; `CComSafeArray` is an ATL wrapper for SAFEARRAYs, and it is used simply to allow easy access to SAFEARRAY elements. This transformation of a vector of double into a vector of VARIANT results more complex than the transformation of non-vectorial variables as explained in the sample code at paragraph 3.3. In this way it has been opened a connection with the statistical software R. Exchange of data, variables and most of all commands, is possible. For this reason the local method calls R (remote) functions to perform the linear regression between the past vector and it calls others commands to store results. In this way the local method can receive the subsequent processed data from the statistical software as well as the graphics and text outputs; this last operation is possible using the *GraphicDevice* and the *CharacterOutputDevice* ActiveX controls. The function that allows all how just explained is quoted in appendix (see appendix B.3).

5.2.2 Exertion classes

The involved classes that perform the exertion calculation and analysis are:

- treeTestView;
- exertionView;
- exertionViewWeekly;
- ExertionCalculator;
- gestorDisc;
- CdialogManager classes.

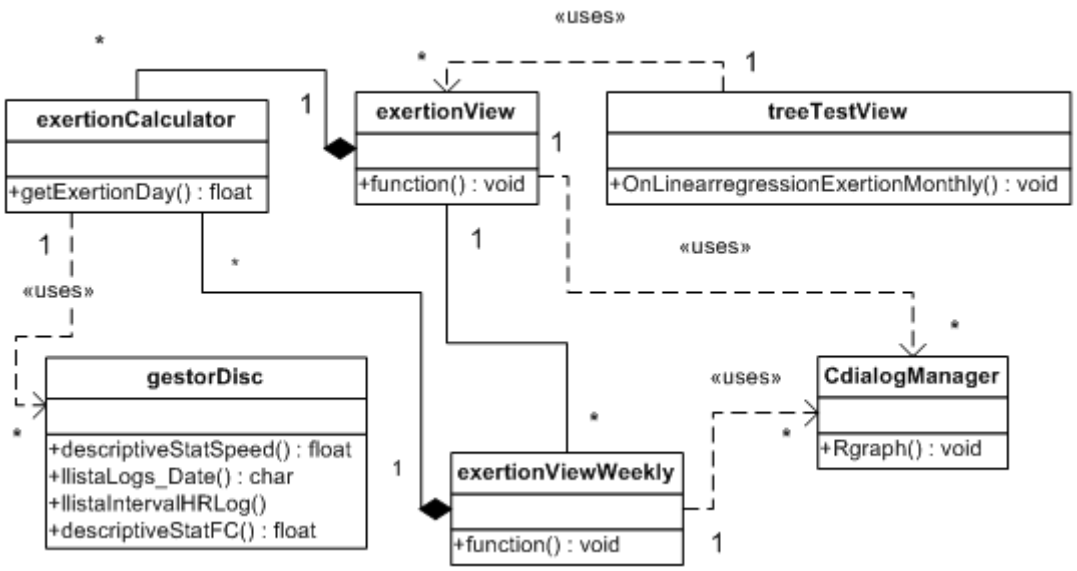


Figure 5.4. UML diagram for exertion

treeTest view class

It retrieves from the system the athlete's name and the identifier of the select log; it passes this parameters to the related method of *exertionView* class.

exertionView class

This class receives the athlete's name from *treeTestView*, it calculates the one month before date and performs one call to the *ExertionCalculator* class for each day of the estimated month. His function is to show to the user the monthly variation of the exertion factor. For each day, the graph shows others correlated values as maximum and average HR and maximum and average speed, too. Furthermore, it retrieves from *ExertionCalculator* other parameters that will be past to the appropriate graphic class to perform a interesting linear regression between exertion values and HR or speed. This class shows the HR intervals of the athlete, the related default exertion factors, the sport factor and it allows the user to update them. In this case, the new exertion calculation will be immediately processed and the graph will be automatically updated. A list control implements

a summary containing all parameters related to a single day (date, exertion value, maximum and average speed, maximum and average HR). Finally, it is able to afford buttons to change the analyzed period and to select a previous one (30 days before).

The most important implemented method is:

```
void function(int defVectToUse)
```

This is the core function of the class. It calculates the one month before date; starting from this day until today date, it performs a call for day to *ExeertionCalculator* and it retrieves from it the day exertion value, the maximum and average HR and speed values. Subsequently, it works on the graph view and, using the *NTGraphCtrl* ActiveX control, it shows the monthly exertion values and the related average HR.

exertionViewWeekly class

Fundamentally, this class works as *exertionView* class. The difference between the two classes is that *exertionViewWeekly* has a different time setting and for this reason works only about a week before the today date and not about a month.

ExertionCalculator class

It represents an intermediate point between the *exertionView* class and the *gestorDisc* one. It contains the exertion calculation algorithm based on the user guide of POLAR Precision Performance Software [2] (see paragraph 4.1). It is essentially composed by a unique function that is called by *exertionView* or *exertionViewWeekly* and receives the athlete's id, the selected date, a exertion factors vector and a value representing the sport factor. It interrogates the DB to obtain all logs that behave to the selected day and then it retrieves the time spent for each HR interval of all logs. These are the basic values of the exertion calculation. It implements the algorithm and it stores the result into a special structure. It is important to notice that if there is more than one log in a day, the related exertion values are calculated and added. It also stores average HR, maximum

HR, average speed and maximum speed of a day, obviously managing the fact that it is possible to have more logs in a day.

gestorDisc class

It passes data (which are stored in a vector [9]) to *ExertionCalculator*. In this case they can be descriptive statistics, log identifiers or HR interval structure. The implemented methods are:

`llistaLogs_Date(string idU,string date)`

It returns logs that behave to a particular athlete in a particular date.

`llistaIntervalHRLog(string idLog, string idU)`

This function returns an HR intervals list associate to a specific log. It stores results into a particular structure called `registre_intervalHRLog` which contains maximum and minimum HR, the log ID, the user ID and the time value.

About descriptive statistics, there are the following methods, already described into the "Linear Regression" section (5.2.1):

`descriptiveStatSpeed (string idLog, string idU)`

Speed average, maximum and minimum values.

`descriptiveStatFC (string idLog, string idU)`

HR average, maximum and minimum values.

CdialogManager classes

Following classes belong to this category:

- RgraphExertionHRMax;
- RgraphExertionMeanHR;
- RgraphExertionMaxSpeed;
- RgraphExertionMeanSpeed.

They implement a linear regression view. Each class shows a couple of different variable, but their code structure and functioning is the same. Their function is essentially to display parameters that they receive from *exertionView* or *exertionViewWeekly*. In particular they are the vectors of exertion and the selected parameter values.

5.2.3 Gradient classes

The involved classes that perform the exertion calculation and analysis are:

- treeTestView;
- gradientView;
- gradientViewDetail;
- gestorDisc;
- CdialogManager classes.

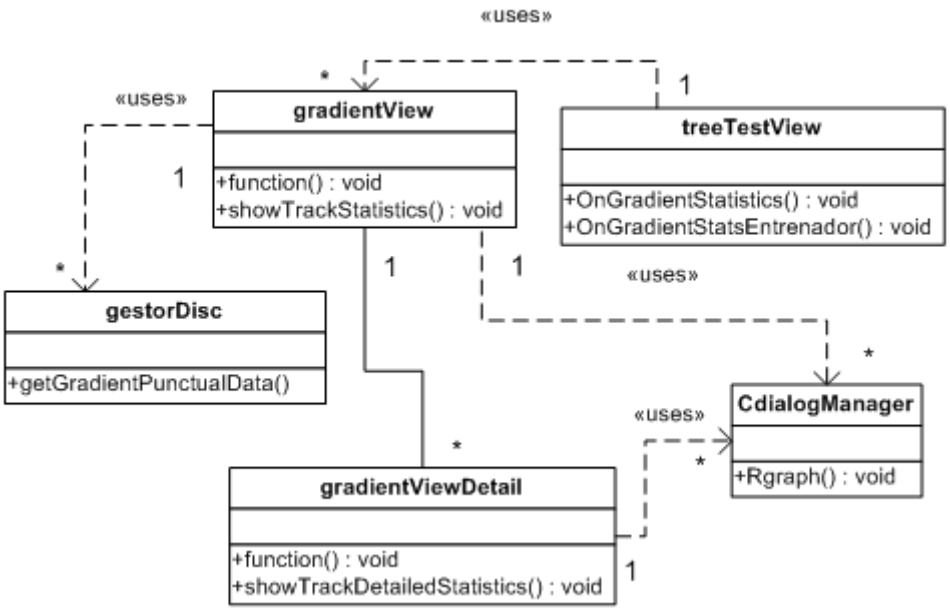


Figure 5.5. UML diagrams for gradient

treeTestView class

It has got simple methods which retrieve from the system the athlete's name and the log identifier and pass these parameters to *gradientView* class.

gradientView class

This class receives the athlete's name and the log identifier from *treeTestView* and it calls the *gestorDisc* class to obtain the log structured data. Subsequently, *gradientView* implements the "gradient algorithm" described at paragraph 4.2, who, starting from the altitude track profile, groups segments which have the same or the similar gradient value; it approximates this value sequence using a line segment. In this way, the new obtained track profile is composed by a sequence of line segments. It also shows to the user this new profile, as well as the calculated segment parameters and statistics. Users can obviously update the gradient angular limit and the software automatically reuses the gradient algorithm to calculate, to process and finally to show the new track profile and related statistics. A list control implements a summary containing all parameters related to a gradient range of values (minimum and maximum gradient values, number of segments that belong to this range, percentage respect to the total line segments of the track, maximum and average speed, maximum and average HR). The implemented most important methods are:

```
void function()
```

It implements the "gradient algorithm" and it allows the user to see the track profiles.

```
void showTrackStatistic()
```

It is a very useful method which counts the number of track line segments which belong to a particular gradient range and all the related parameters already commented. Users can understand immediately the track gradient profile only watching these statistics.

gradientViewDetail class

This class receives the data to display, already processed by *gradientView*. These data are on form of vectors: the first contains punctual data of the track and the second one contains parameters of each line segment. A list control implements a summary containing all parameters related to a single line segment (starting and final distance, starting and final altitude, gradient, maximum, minimum and average speed, maximum, minimum and average HR, maximum, minimum and average energy consumption). Furthermore, it performs interesting linear regressions between segment gradient values and HR, speed and energy consumption related to each segment.

gestorDisc class

Its function is to interrogate the database. It selects the logs' data and store them in a particular structure called `gradient_punctual_data`. The implemented method is:

`getGradientPunctualData(string usID, string logID)`

It returns logs punctual data of altitude, distance, HR, energy consumption and speed.

CdialogManager classes

Following classes belong to this category:

- RgraphGradientHR;
- RgraphGradientSpeed;
- RgraphGradientEnergy.

They implement a linear regression view, exactly in the same way already explained for the linear regression CdialogManager classes at 5.2.1.

5.2.4 Bend classes

The involved classes that perform the exertion calculation and analysis are:

- treeTestView;
- bendView;
- bendViewDetail;
- gestorDisc;
- CdialogManager classes.

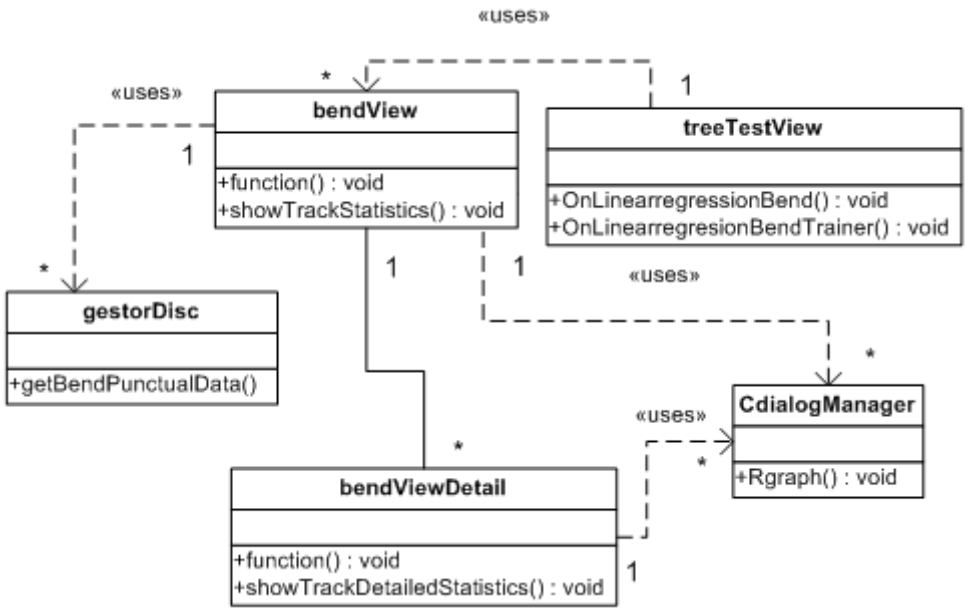


Figure 5.6. UML diagram for bend

treeTestView class

It retrieves from the system the athlete's name and the log identifier and it passes these parameters to *bendView* class.

bendView class

Bendview class implements the "bend algorithm" described at paragraph 4.3, which, starting from the topographic track coordinates, establishes which points create a bend; then it stores its side (respect to the starting point) and many others related data. Two important parameters are involved into this calculation: the bend length and the minimum bend angle. They can be modified by users. This class shows the track profile, as well as the calculated bend parameters and statistics. There are also two list controls that implement summaries containing all parameters related to a bend. The first summary shows data as minimum and maximum angle, percentage of bends respect to the total, average HR, average speed, average gradient, left bends which belong to the interval, right bends and total bends. This first list is grouped by angular intervals, while the second one is grouped by gradient range of values. This one shows minimum and maximum gradient, percentage of bends respect to the total, average HR, average speed, average bend angle, left bends, right bends and total bends. Furthermore, *bendView* shows descriptive statistics about gradient and plan angles. The most important implemented methods are:

`void function()`

It implements the "bend algorithm" and it allows users to see the track profile and bends data.

`void showTrackStatistic()`

This is a very useful method, which counts the general statistics and date groped by gradient and plan angular intervals. Users can understand immediately the track gradient profile only watching these statistics.

bendViewDetail class

This class receives the data to display, already processed by *bendView*. These data are on form of vectors: the first contains punctual data of the track and the second one contains parameters of each bend. A list control implements a summary containing all parameters related to a single bend (distance from the start point, altitude, side, angle, gradient, HR,

speed and energy consumption). Furthermore, it performs linear regressions between:

- HR and angle;
- HR and gradient;
- Speed and angle;
- Speed and gradient;
- Angle and gradient.

gestorDisc class

Its function is to interrogate the database. It selects the selected log's data and store them in a particular structure called `bend_punctual_data`. The implemented method is:

`getBendPunctualData(string usID, string logID)`

It returns logs punctual data of altitude, HR, energy consumption and speed.

CdialogManager classes

The following classes belong to this category:

- RgraphBendHRAngle;
- RgraphBendHRGradient;
- RgraphBendSpeedAngle;
- RgraphBendSpeedGradient;
- RgraphBendAngleGradient.

They implement a linear regression view, exactly in the same way already explained for the linear regression CdialogManager classes at 5.2.1.

5.3 Model of behaviour

This model is a useful instruments to determine how the system reacts to users' actions. Each operation generates a system state modification, that can be the requested operation execution or an exception if some conditions are not satisfied.

5.3.1 Operations

Name:	To execute linear regression
Semantics:	To execute a linear regression of the selected log
Exceptions:	Error message if preconditions are not satisfied
Preconditions:	Log must exist into the database
Post conditions:	The linear regression has been performed

Name:	To select the exertion view
Semantics:	To display the exertion statistics of an athlete
Exceptions:	Error message if preconditions are not satisfied
Preconditions:	Athlete must exist into the database
Post conditions:	Exertion statistics have been visualized

Name:	To select the gradient view
Semantics:	To display the gradient statistics of a log
Exceptions:	Error message if preconditions are not satisfied
Preconditions:	Log must exist into the database
Post conditions:	Gradient statistics have been visualized

Name:	To select the bend view
Semantics:	To display the bend statistics of a log
Exceptions:	Error message if preconditions are not satisfied
Preconditions:	Log must exist into the database
Post conditions:	Bend statistics have been visualized

5.4 Sequence diagrams

Sequence diagrams are a very useful instrument to model the functions of the system. They represent at high level which are the operation system and which classes are involved in. Time is a fundamental factor of this kind of diagram, and it is represented on the vertical axis. Furthermore one can observe the method calls of each class and their temporal schedule.

Following diagrams show the main implemented system operations.

5.4.1 Linear regression diagram

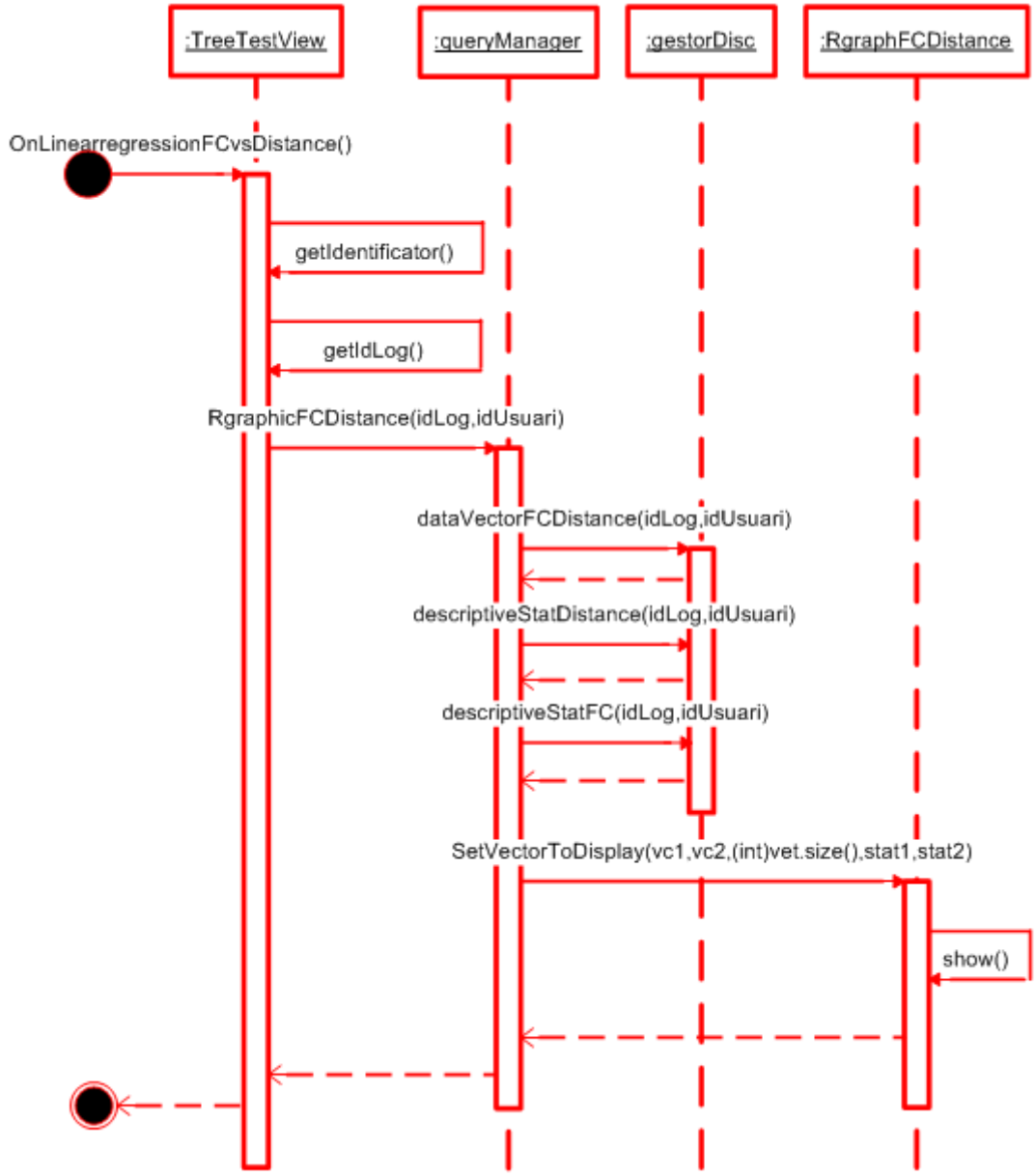


Figure 5.7. Sequence diagram of linear regression

5.4.2 Monthly exertion diagram

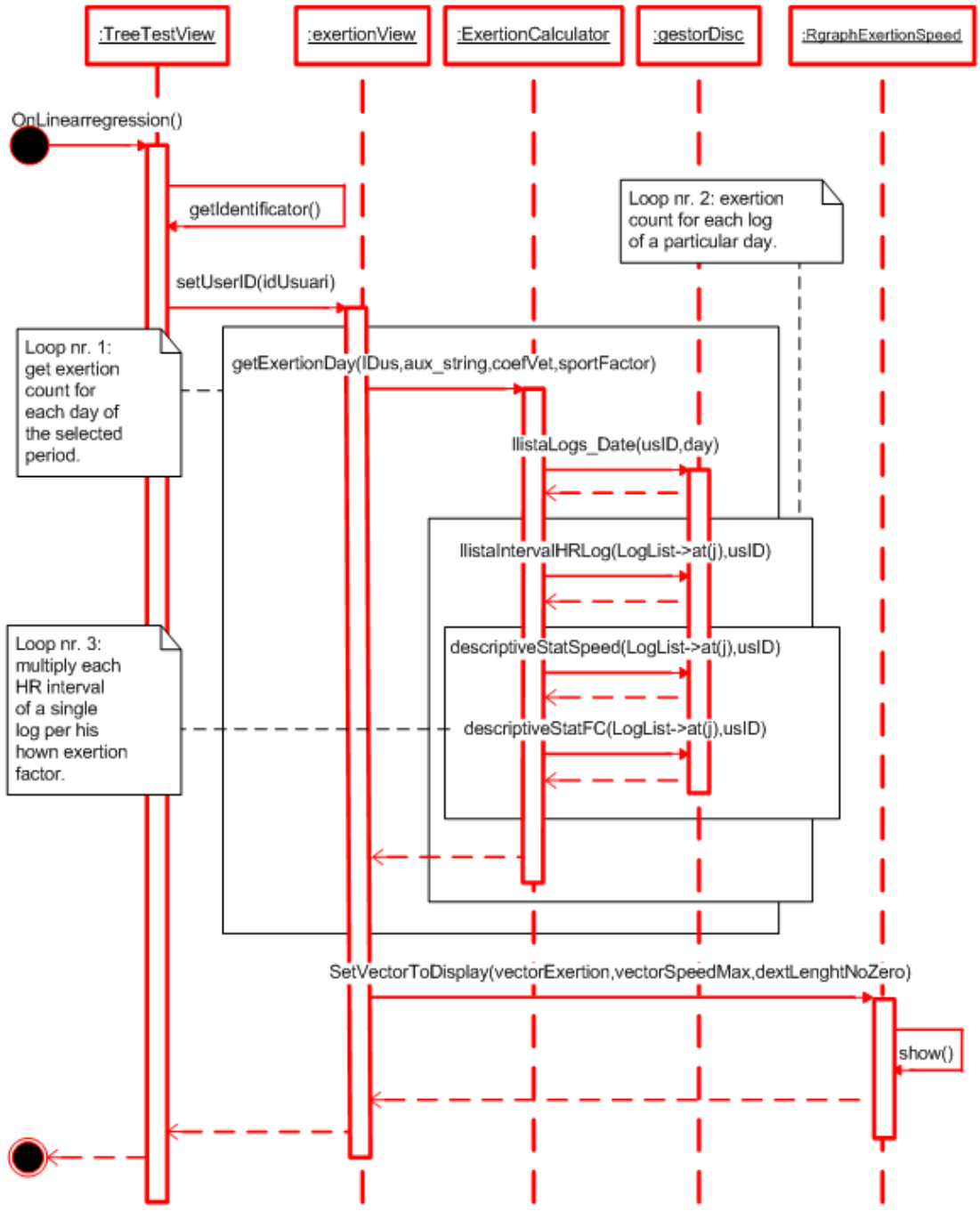


Figure 5.8. Sequence diagram of monthly exertion

5.4.3 Weekly exertion diagram

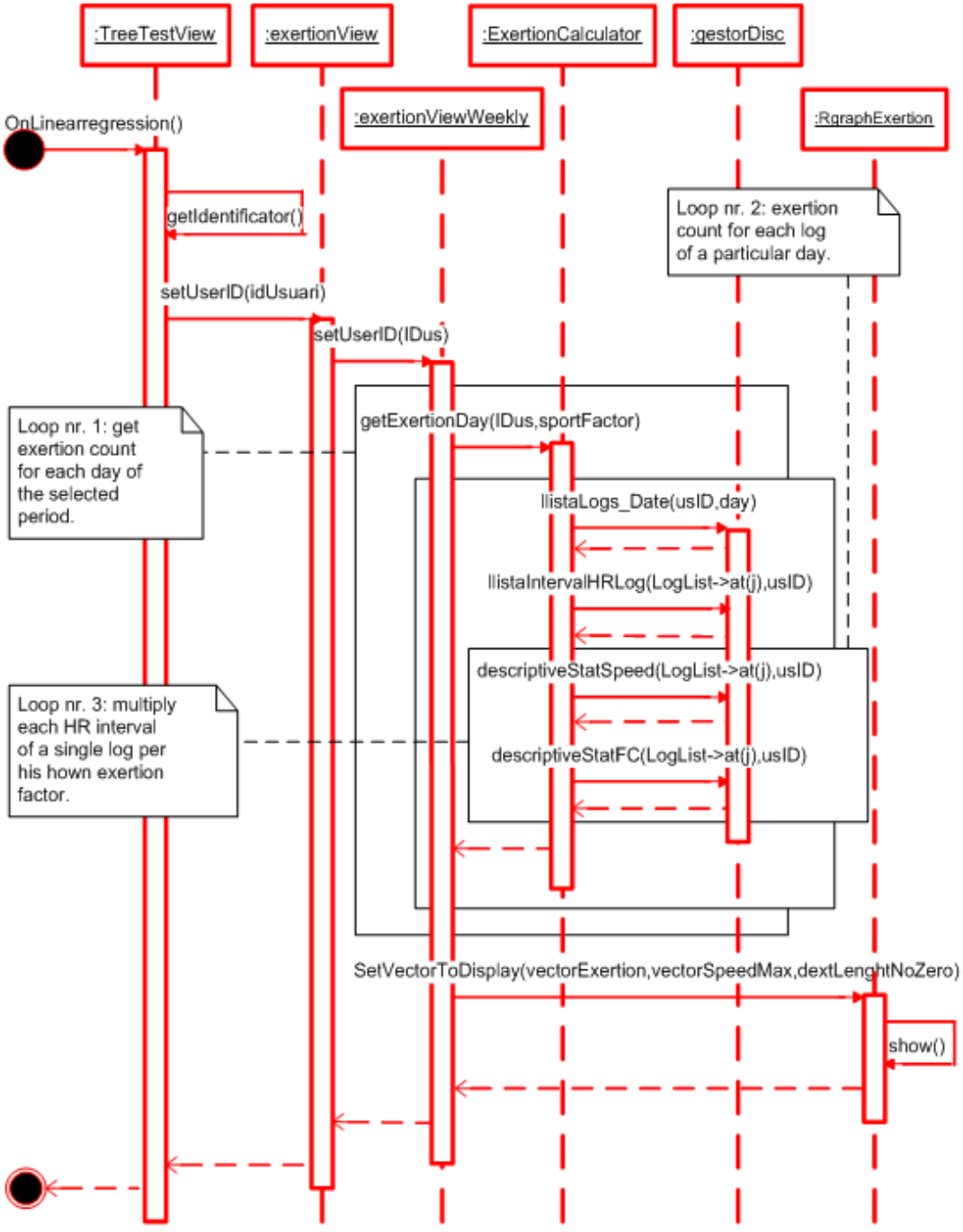


Figure 5.9. Sequence diagram of weekly exertion

5.4.4 Gradient diagram

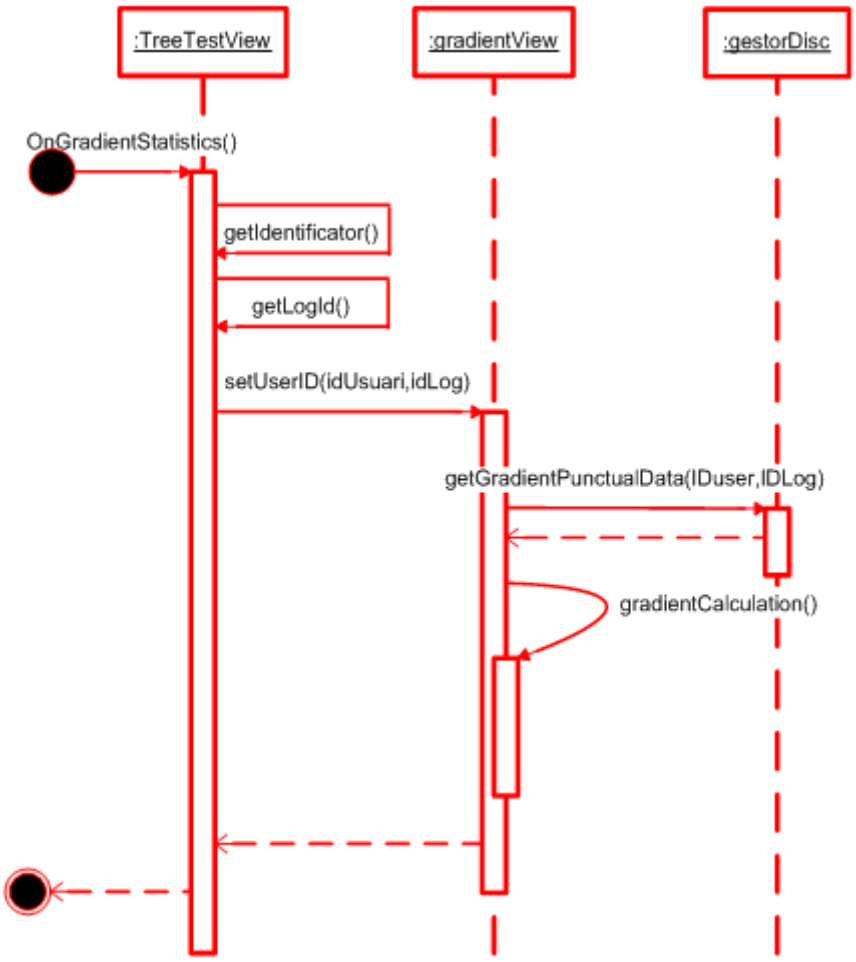


Figure 5.10. Sequence diagram of gradient view

5.4.5 Detailed gradient diagram

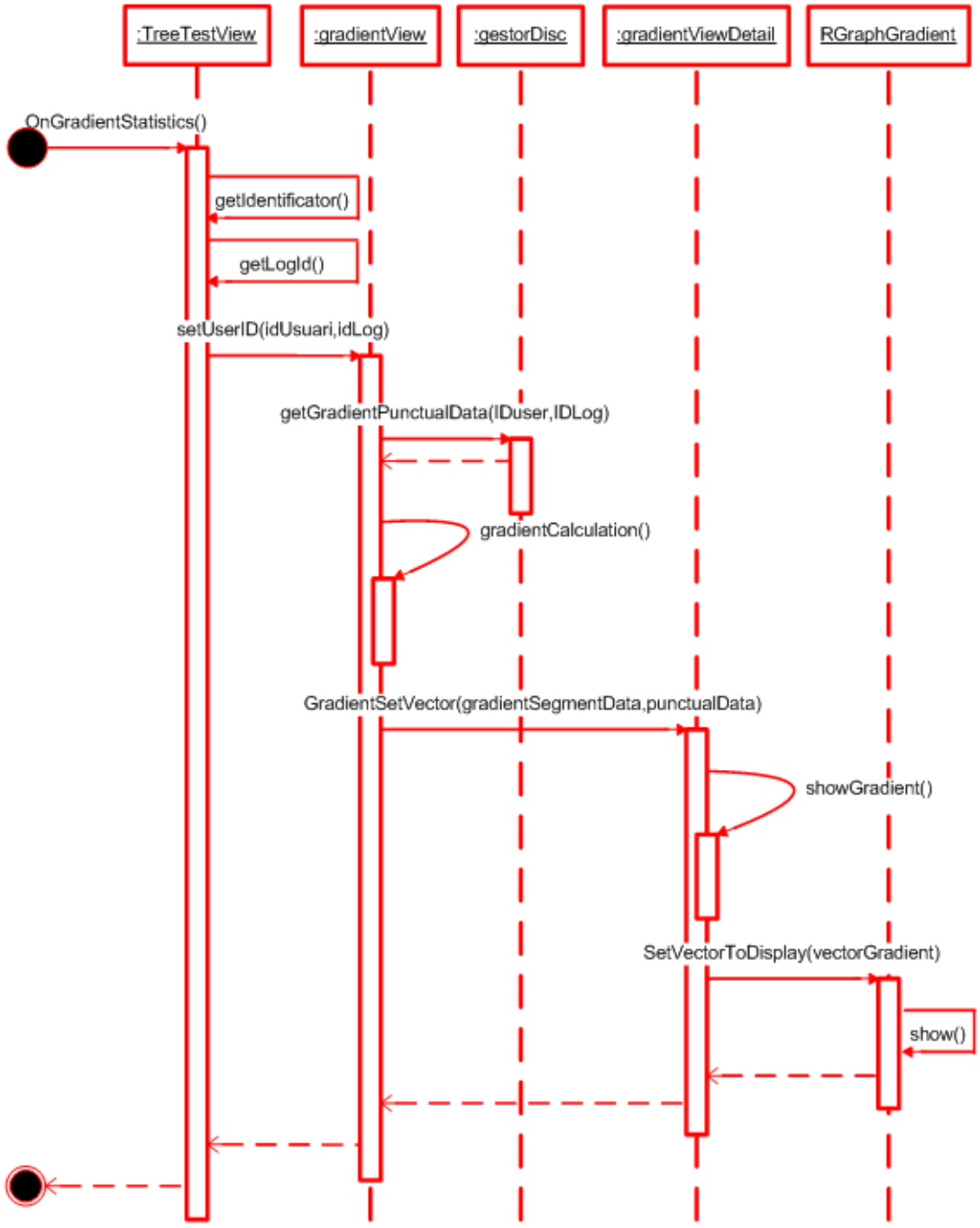


Figure 5.11. Sequence diagram of detailed gradient view

5.4.6 Bend diagram

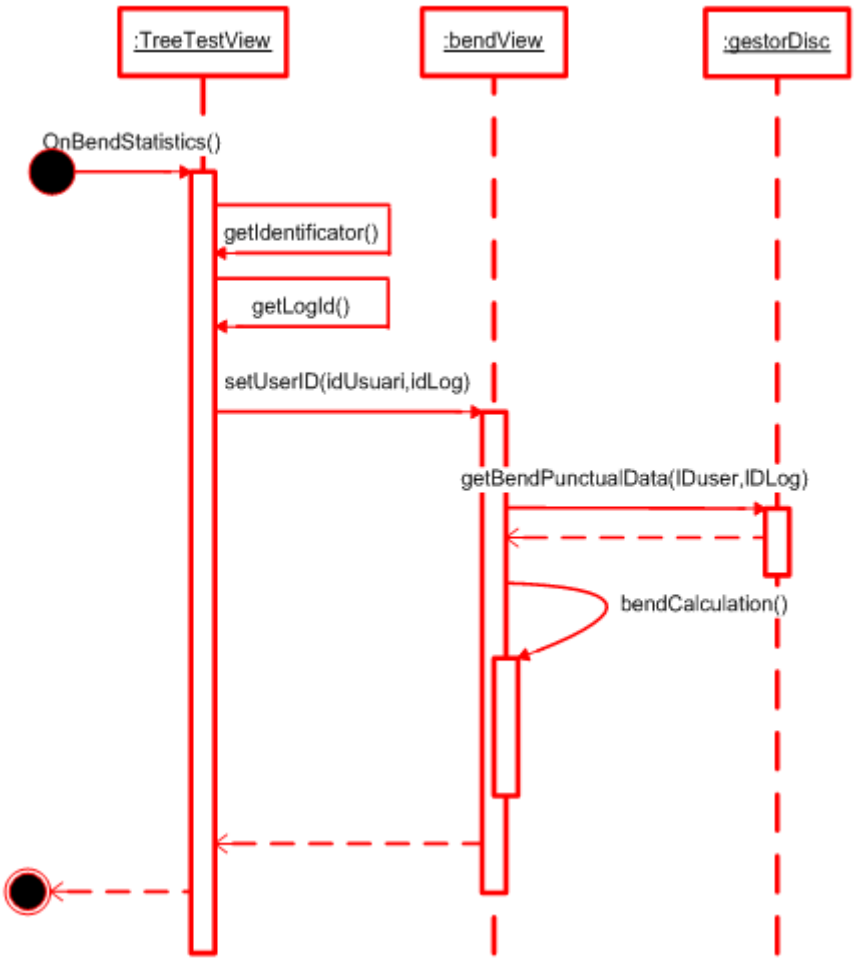


Figure 5.12. Sequence diagram of bend view

5.4.7 Detailed bend diagram

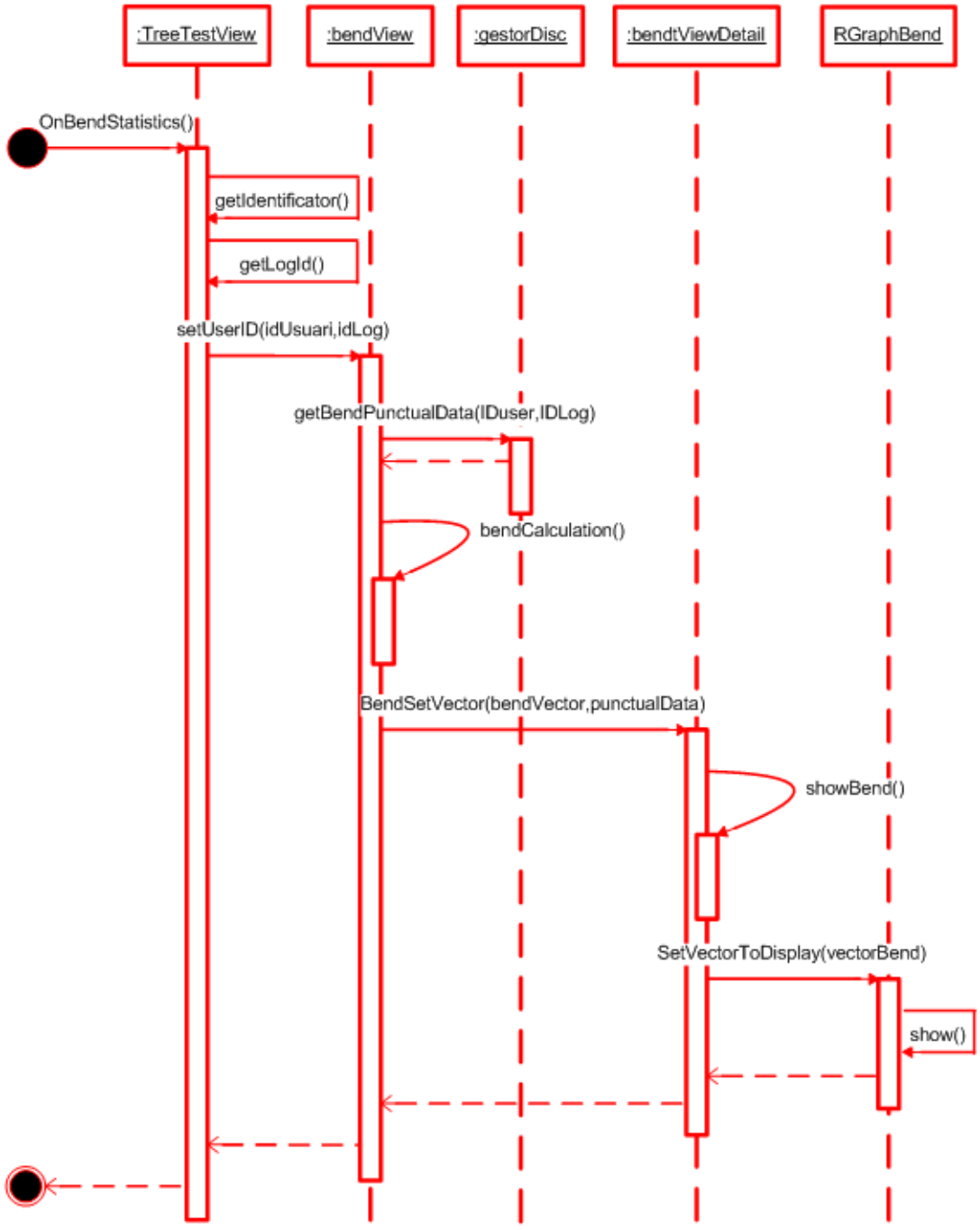


Figure 5.13. Sequence diagram of detailed bend view

5.5 Setup creation

Finally, to complete this thesis work, a setup project has been developed [10]. The framework Visual Studio 2005 allows developers to create an installer for their program. This is a very useful tool that helps programmers to do a more complete work and, most of all, it helps them in the software distribution.

Setup Project is composed by five useful editors:

1. **File system editor:** it allows user to choose and organize files and folders that will be installed on a PC. The paths of every component can be choose and furthermore it involves a shortcut creation to the program on the user's *Desktop* and on the user's *Program Menu* and the association with related icons.

2. **Registry editor:** useful to write *keys* on Target user's machine registry. Keys are values that programmers want to store in the user's PC registry because they give some information about the software. They are usually parameters such as the software version and they are very important because they can be read and tested during the installation phase of any software.

3. **User interface editor:** it is used to display information about installation state. It provides for the standard dialogs that being displayed into all the three installation phases: *start*, *progress* and *end*. Text to be displayed can be easily and rapidly edited using the provided menu.

4. **Custom Action editor:** it allows to add actions to be performed during a particular installation/uninstallation state (*install*, *commit*, *rollback*, *uninstall*). The programmer can add actions to be executed, depending on the state in which the installation is in. For example, this operations are very important when something goes wrong during the installation phase: in this case, the execution state is set to *rollback* and the machine has to perform some actions to restore the default situation.

5. **Launch Conditions editor:** developer can set conditions, which stop the install execution if they are not verified. Usually, this options are used to check if all prerequisites of the program are correctly installed. To perform this test, it is necessary to check some registry key entry.

By using the described editors, a Setup project has been implemented in order to improve +Atleta software distribution. In this way, professors and students can run +Atleta and observe the actual development state and test new introduced features. The setup program is useful to perform a fast installation of +Atleta and all additional components that are needed.

More in detail, +Atleta Setup Project main characteristics are:

- **prerequisites check:** installation is allowed only if prerequisites are present. The most important is the .NET framework version 3.0. If the installer does not find it, a warning message is displayed and the user can choose if download and install the missing component. If the user accept, an automatic download starts and solves the problem. Otherwise the installation is blocked and cancelled. The prerequisites check has been performed as a *launch condition*, which checks if a key related to the .NET framework is present into the local PC registry.

- **Setup specifications:** the *user interface editor* has been utilized to create dialog boxes in which users can choose installation's details. In particular, they ask for additional components that are needed to the correct functioning of +Atleta. User can select his/her favorite options about installation folder, too. Additional components required are:

  - R;
  - R Server;
  - MySQL Server;
  - MySQL .Net Connector;
  - Cortona Viewer.

To install these components *custom actions* have been created.

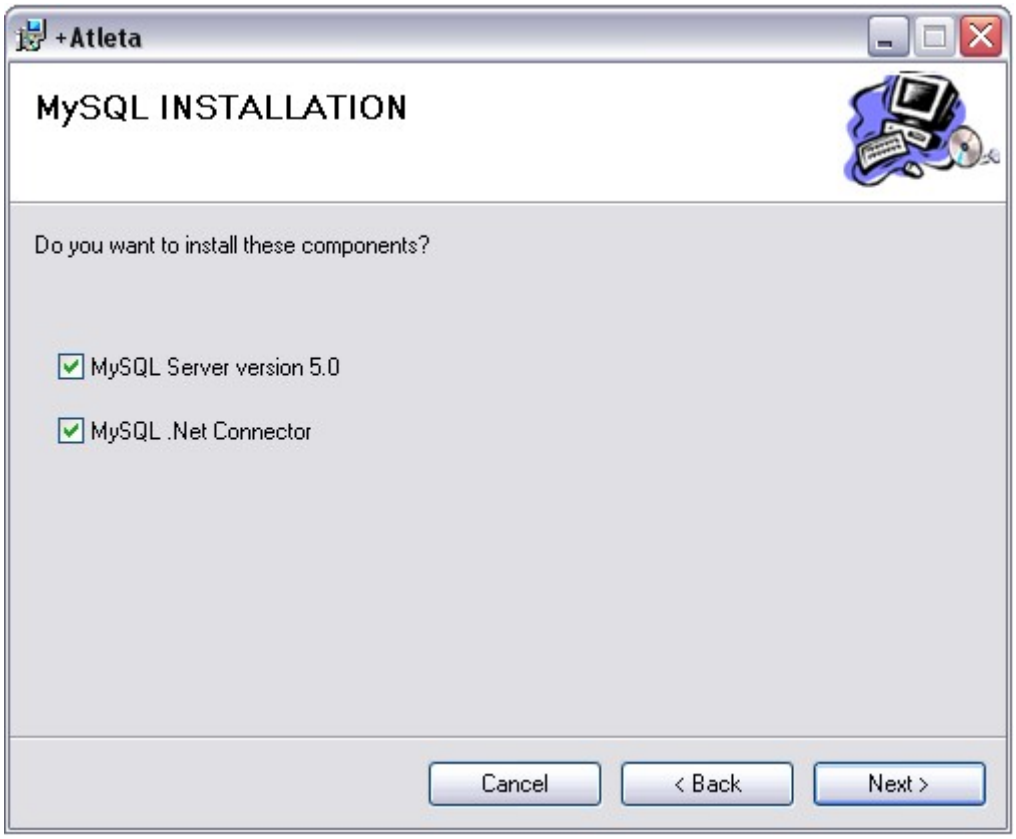


Figure 5.14. Screenshot of +Atleta installer

- **File system options:** using the *file system editor* above described, the files system organization has been chosen by the undersigned. In particular, the program folder, called "+Atleta project", contains all files and libraries used by the program. Furthermore, during the installation process, a Desktop shortcut and a entry in the user's program menu are created.

Chapter 6

Conclusions

As to conclusions, this thesis activity has added new and important capabilities to +Atleta software. In particular, a whole statistical data analysis structure has been created. It performs the linear regression of data stored into the database. Through a special user interface, it is possible to choose on which data the linear regression has to be performed. Automatically, in few instants, the system provides to establish the R connection, to send the information that are needed and to receive processed data. They are displayed to the user as graphs, together with the most important associated data. Linear regression is not performed on all available biological data, but only on selected data which have a certain relevance in sports and medical subjects. The goal of this work has not been to perform deep and complex statistical analysis, but, it has been to create a efficient functioning infrastructure which performs this analysis. In this way, a solid base has been build for future researchers. They will cooperate to the project and they will use this useful instrument. Thanks to this detailed documentation, they can make full use of the great potential of the statistical software R. Furthermore, an important part of this work was the planning and the creation of three algorithm of data analysis. They are related to athlete's exertion, track's gradient and bends of the training way respectively. These analysis are referred to particular tricky aspects about athletics training and their goal is to show some detailed statistics. Moreover, they calculate parameters which can be used as input for the DSS' simulator engine. It will be implemented in the next years in order

to know in advance future athlete's performances. Finally, as to simplify distribution and use, an installer for Microsoft operating system has been developed. It installs in few steps +Atleta , the MySQL database and all the components that are needed by the software to its correct functioning.

As software component development are concerned, the architectural aspect has been managed in order to follow a programming modular approach. By using this method, a certain extendibility has been added, too. In this way, it is possible to add new capabilities to the project, without any change in the architecture. Since it was important to follow the project guideline, one of the most important leading principle of this work has been the compatibility of the components with the existing system, also at presentation level. Another planning strategy has been to continue to use worldwide standard to develop every component. An example of this strategy is the connection between R and +Atleta by R-server, which is a frequently updated and developed instrument. It guarantees great longevity to the whole project. Another example is the ActiveX technology use for all graph's visualization. Finally, user-interfaces have been developed by following simplicity, intuitiveness and immediacy of use criteria. Each interface has been planned to have two precision levels: the first level contains main information and data summaries which are divided into categories. The second one, more detailed and complete, shows all information about the selected topic.

As it has previously said many times in the all document, my work's contribution at the +Atleta project has been focused on the completion of the whole system infrastructure. Nowadays, the project is still into development phase and there are numerous researchers working on it, each one working on a specific aspect. There are many areas of interest that are focused both on the development of new capabilities and on the improvement of existing mechanisms. An example is the data exchange between system and professional training computers, which is not very automatic and simple as should be for a software that want to achieve a large number of users. Furthermore, the work that has been done was focused only on the system functioning on a single computer. Some researchers are creating a distributed system, which will allow to access to the system functionalities by

web; in this case, the traditional architecture will be transformed following a client-server model. In other words, there will be a marked division between the software system engine and the database.

+Atleta project has two future perspectives: the first one is a short-term project, while the second is a long-term one. In the next two or three years, the completion of the general project, the set up of the software simulator and the DSS are planned to reach their conclusions. Within this data, all the functions will be extended to many other athletics disciplines. As regards the long-term perspective, it is expected to do a medical application, once the system proves to be perfectly operable on athletes. Once that data related to a healthy body are well known, the idea is that all those parameters which are so different from these data could be symptoms of pathologies. As a consequence, +Atleta could be a useful medical application.

Appendix A

Database specifics

This section is dedicated to describe each table contents.:

ACTIVITATS

This table allows to save the name of user activity.

FIELD	DATA TYPE	NOTE	DESCRIPTION
nomActivitat	VARCHAR(25)	PK	User activity name
identificador	VARCHAR(25)	PK FK (Usuari)	User identifier

ENTRENADOR

This table allows to save entrenador user information.

FIELD	DATA TYPE	NOTE	DESCRIPTION
identificador	VARCHAR(25)	PK FK (Usuari)	User identifier

ASSOCIA_LOG_PLA

This table allows to save association information about a log and a system plan.

FIELD	DATA TYPE	NOTE	DESCRIPTION
idLog	VARCHAR(14)	PK FK (Log)	Log identifier of this User
nomPla	VARCHAR(25)	PK FK (Pla)	System plan name associated to this log
identificadorUsuari	VARCHAR(25)	PK FK (Log)	User identifier of the Log
identificadorPla	VARCHAR(25)	PK FK (Pla)	User identifier of the system plan

INFOASSOCIADA

This table allows to save sample information retrieved by the training computers, registered every sample time.

FIELD	DATA TYPE	NOTE	DESCRIPTION
id	VARCHAR(14)	PK	Sample identifier (UNIQUE) related to a particular Log
hora	TIME	NOT NULL	Sample time
durada	TIME		Past time from the start time
HRmig	UNSIGNED INT(3)		Sample Heart Frequency (expressed in beat per minute)
distancia	DECIMAL		Sample distance from the start (expressed in meter)
Velocitat Mitjana	DECIMAL		Mean sample speed (express in min per Km)
EPOC	DECIMAL		Sample EPOC from the start (expressed in ml/Kg)
altitud	DECIMAL		Sample altitude (expressed in meter)
Energia Consumida	UNSIGNED DECIMAL		Energy consumption (expressed in Kcal)
idLog	VARCHAR(14)	PK FK (LogExtern)	Log identifier
identificador Usuari	VARCHAR(25)	PK FK (Usuari)	User identifier

ASSOCIA_LOG_PLA_PLANIFICAT

This table allows to save association information about a log and a system plan scheduled in a particular date.

FIELD	DATA TYPE	NOTE	DESCRIPTION
idLog	VARCHAR(14)	PK FK (Log)	Log identifier of this user
nomPla	VARCHAR(25)	PK FK (PlaPlanificat)	System plan name associated to this log with this user
identificador Usuari	VARCHAR(25)	PK FK (Log)	User identifier of the Log
identificador Pla	VARCHAR(25)	PK FK (PlaPlanificat)	User identifier of the system plan
dia	VARCHAR(8)	PK FK (PlaPlanificat)	System plan date

ASSOCIA_LOG_PLA_PROGRAMA

This table allows to save association information about a log, a system plan and a training plan.

FIELD	DATA TYPE	NOTE	DESCRIPTION
idLog	VARCHAR(14)	PK FK (Log)	Log identifier of this user
nomPla	VARCHAR(25)	PK FK (PlaPrograma)	System plan name associated to this log with this user
Identificador Usuari	VARCHAR(25)	PK FK (Log)	User identifier of the Log
Identificador Pla	VARCHAR(25)	PK FK (PlaPrograma)	User identifier of the system plan
nomPrograma	VARCHAR(25)	PK FK (PlaPrograma)	System training plan name

ATLETA

This table allows to save atleta user information.

FIELD	DATA TYPE	NOTE	DESCRIPTION
identificador	VARCHAR(25)	PK FK (Usuari)	User identifier
identificadorEntrenador	VARCHAR(25)	FK (Usuari)	Trainer identifier of this user

INTERVALHR

This table allows to save an Heart Frequency interval.

FIELD	DATA TYPE	NOTE	DESCRIPTION
maxHR	UNSIGNED INT(3)	PK	Maximum interval Heart Frequency (expressed in beat per minute)
colorHR	VARCHAR(10)		Interval display color
identificador	VARCHAR(25)	PK FK (Usuari)	User identifier

INTERVALHR_ATLETA_TEMPS

This table allows to save the total time past in every HR interval of each athlete.

FIELD	DATA TYPE	NOTE	DESCRIPTION
identificador Usuari	VARCHAR(25)	PK FK (Atleta)	User identifier
maxHR	UNSIGNED INT(3)	PK	Maximum interval Heart Frequency (expressed in beat per minute)
minHR	UNSIGNED INT(3)	PK	Minimum interval Heart Frequency (expressed in beat per minute)
tempsZona	TIME		Past time in the related HR interval

LOG MANUAL

This table allows to save a manual log, created by the user.

FIELD	DATA TYPE	NOTE	DESCRIPTION
id	VARCHAR(14)	PK	Log identifier (UNIQUE)
identificadorUsuari	VARCHAR(25)	PK	User log identifier

LOG EXTERN

This table allows to save a system log data, imported from an external XML file.

FIELD	DATA TYPE	NOTE	DESCRIPTION
Id	VARCHAR(14)	PK	Log identifier (UNIQUE) of a user
Identificador Usuari	VARCHAR(25)	NOT NULL	User identifier
horaFi	TIME		Log end time
maxHR	UNSIGNED INT(3)		Maximum log Heart Frequency (expressed in beat per minute)
minHR	UNSIGNED INT(3)		Minimum log Heart Frequency (expressed in beat per minute)
maxAltitud	DECIMAL (12,3)		Maximum log altitude (expressed in meter)
minAltitud	DECIMAL (12,3)		Minimum log altitude (expressed in meter)
distAscendent	DECIMAL (12,3)		Log covered rising distance (expressed in meter)
distDescendent	DECIMAL (12,3)		Log covered falling distance (expressed in meter)
distPla	DECIMAL (12,3)		Log covered plan distance (expressed in meter)
tempDiscendent	TIME		Log rising time
tempAscendent	TIME		Log falling time
tempsPla	TIME		Log plain time
velocitatMinima	DECIMAL (12,2)		Minimum log speed (express in min per Km)
velocitatMaxima	DECIMAL (12,2)		Maximum log speed (express in min per Km)
intervalMostreig	TIME		Sampling time

INTERVALHR_LOG

This table allows to save the log time past in every HR interval of each athlete.

FIELD	DATA TYPE	NOTE	DESCRIPTION
identificador Usuari	VARCHAR(25)	PK	User identifier
idLog	VARCHAR(14)	PK	Log identifier
maxHR	UNSIGNED INT(3)	PK	Maximum interval Heart Frequency (expressed in beat per minute)
minHR	UNSIGNED INT(3)	PK	Minimum interval Heart Frequency (expressed in beat per minute)
tempsZona	TIME		Past time in the related HR interval

INTERVALHR_LOG_MARCA

This table allows to save the log time past in every HR interval of each athlete, divided by label.

FIELD	DATA TYPE	NOTE	DESCRIPTION
identificadorUsuari	VARCHAR(25)	PK	User identifier
idLog	VARCHAR(14)	PK	Log identifier
idMarca	VARCHAR(25)	PK	Label identifier
idLogMarca	VARCHAR(12)	PK	Log and Label identifier
idUsuariMarca	VARCHAR(25)	PK	User and Label identifier
maxHR	UNSIGNED INT(3)	PK	Maximum interval Heart Frequency (expressed in beat per minute)
minHR	UNSIGNED INT(3)	PK	Minimum interval Heart Frequency (expressed in beat per minute)
tempsZona	TIME		Past time in the related HR interval

LOG

This table allows to save a system log data.

FIELD	DATA TYPE	NOTE	DESCRIPTION
id	VARCHAR(14)	PK	Log identifier (UNIQUE)
Identificador Usuari	VARCHAR(25)	NOT NULL PK	User identifier
nomLog	VARCHAR(25)	NOT NULL	Log name
activitat	VARCHAR(25)	NOT NULL	Activity name
data	DATE	NOT NULL	Log date
horalnici	TIME	NOT NULL	Log start time
durada	TIME	NOT NULL	Log duration
distancia	UNSIGNED DECIMAL	NOT NULL	Log distance (expressed in meter)
mitjanaHR	UNSIGNED INT(3)	NOT NULL	Mean log Heart Frequency (expressed in beat per minute)
HRrepos	UNSIGNED INT(3)		User rest Heart Frequency related to this log date (expressed in beat per minute)
pes	UNSIGNED DECIMAL(3,2)		User weight related to this log date (expressed in Kg)
Sensacio Activitat	UNSIGNED INT(2)		User sensations
Energia Consumida	UNSIGNED DECIMAL		User energy consumption related to this log (expressed in Kcal)
EPOC	DECIMAL		User EPOC related to this log (expressed in ml/Kg)
notes	TEXT		Log notes
temperatura	DECIMAL (2,2)		Log temperature (expressed in °C)
Pressio Atmosferica	DECIMAL		Atmospheric pressure (expressed in Bar)
Velocitat Mitjana	DECIMAL (3,2)		Mean speed related to this log (expressed in min per Km)

MARQUES

This table allows to save a particular label data, splitted from a log.

FIELD	DATA TYPE	NOTE	DESCRIPTION
id	VARCHAR(12)	PK	Label identifier (UNIQUE) of log
idLog	VARCHAR(14)	PK FK (LogExtern)	Log identifier
Identificador Usuari	VARCHAR(25)	PK FK (LogExtern)	User identifier
hora	TIME	NOT NULL	Label start time
durada	TIME		Label duration
HRmig	UNSIGNED INT(3)		Mean label Heart Frequency (expressed in beat per minute)
maxHR	UNSIGNED INT(3)		Maximum label Heart Frequency (expressed in beat per minute)
minHR	UNSIGNED INT(3)		Minimum label Heart Frequency (expressed in beat per minute)
distancia	DECIMAL		Label distance (expressed in meter)
minAltitud	DECIMAL		Minimum label altitude (expressed in meter)
maxAltitud	DECIMAL		Maximum label altitude (expressed in meter)
Dist Descendent	DECIMAL		Label covered falling distance (expressed in meter)
Dist Ascendent	DECIMAL		Label covered rising distance (expressed in meter)
distPla	DECIMAL		Label covered plain distance (expressed in meter)
tempsDesc	TIME		Label rising time
tempsAsc	TIME		Label falling time
tempsPla	TIME		Label plain time
velocitatMin	DECIMAL		Minimum label speed (express in min per Km)
velocitatMax	DECIMAL		Maximum label speed (express in min per Km)
velocitatMig	DECIMAL		Mean label speed (express in min per Km)
Energia Consumida	UNSIGNED DECIMAL		Label energy consumption (expressed in Kcal)
notes	TEXT		Log notes

MESURA_TEMPS_LOG

This table allows to save the time of a particular Heart Frequency interval, related to a particular log.

FIELD	DATA TYPE	NOTE	DESCRIPTION
maxHR	UNSIGNED INT(3)	PK FK (IntervalHR)	Maximum intervalHR Heart Frequency (expressed in beat per minute)
idLog	VARCHAR(14)	PK FK (Log)	Log identifier
identificador	VARCHAR(25)	PK FK (IntervalHR)	User IntervalHR identifier
Identificador Log	VARCHAR(25)	PK FK (Log)	User identifier of the log
tempsZona	TIME		IntervalHR duration

MESURA_TEMPS_PLA

This table allows to save the time of a particular Heart Frequency interval, related to a particular system plan.

FIELD	DATA TYPE	NOTE	DESCRIPTION
maxHR	UNSIGNED INT(3)	PK FK (IntervalHR)	Maximum intervalHR Heart Frequency (expressed in beat per minute)
nomPla	VARCHAR(25)	PK FK (Pla)	System plan name
identificador	VARCHAR(25)	PK FK (IntervalHR)	User IntervalHR identifier
identificadorPla	VARCHAR(25)	PK FK (Pla)	User identifier of the system plan
tempsZona	TIME		IntervalHR duration

MESURA_TEMPS_PLA_PLANIFICAT

This table allows to save the time of a particular Heart Frequency interval, related to a particular system plan of a particular date.

FIELD	DATA TYPE	NOTE	DESCRIPTION
maxHR	UNSIGNED INT(3)	PK FK (IntervalHR)	Maximum intervalHR Heart Frequency (expressed in beat per minute)
dia	DATE	PK FK (PlaPlanificat)	System plan date
nomPla	VARCHAR(25)	PK FK (PlaPlanificat)	System plan name
identificador	VARCHAR(25)	PK FK (IntervalHR)	User IntervalHR identifier
Identificador Pla	VARCHAR(25)	PK FK (PlaPlanificat)	User identifier of the system plan
tempsZona	TIME		IntervalHR duration

MESURA_TEMPS_PLA_PROGRAMA

This table allows to save the time of a particular Heart Frequency interval, related to a particular system plan, which behave to a particular training plan.

FIELD	DATA TYPE	NOTE	DESCRIPTION
maxHR	UNSIGNED INT(3)	PK FK (IntervalHR)	Maximum intervalHR Heart Frequency (expressed in beat per minute)
nomPrograma	VARCHAR(25)	PK FK (PlaPrograma)	System training plan name
nomPla	VARCHAR(25)	PK FK (PlaPrograma)	System plan name associated to the training plan
identificador	VARCHAR(25)	PK FK (IntervalHR)	User IntervalHR identifier
Identificador Pla	VARCHAR(25)	PK FK (PlaPlanificat)	User identifier of the system plan
tempsZona	TIME		IntervalHR duration

PLA

This table allows to save a system plan.

FIELD	DATA TYPE	NOTE	DESCRIPTION
nomPla	VARCHAR(25)	PK	Plan name
identificador	VARCHAR(25)	PK FK (Usuari)	User plan identifier
activitat	VARCHAR(25)	NOT NULL FK (Activitats)	Activity name
durada	TIME		Plan duration
distancia	UNSIGNED DECIMAL		Plan distance (expressed in meter)
notes	TEXT		Plan notes

PLAPLANIFICAT

This table allows to save a system plan, related to a particular calendar date.

FIELD	DATA TYPE	NOTE	DESCRIPTION
nomPla	VARCHAR(25)	PK	Plan name
identificador	VARCHAR(25)	PK FK (Usuari)	User plan identifier
dia	DATE	PK	Plan date
activitat	VARCHAR(25)	NOT NULL FK (Activitats)	Activity name
durada	TIME		Plan duration
distancia	UNSIGNED DECIMAL		Plan distance (expressed in meter)
notes	TEXT		Plan notes

PROGRAMMAENTRENAMENT

This table allows to save the system training programs.

FIELD	DATA TYPE	NOTE	DESCRIPTION
nomPrograma	VARCHAR(25)	PK	Training program name
identificador	VARCHAR(25)	PK FK (Usuari)	Training program identifier

PLAPROGRAMA

This table allows to save a system plan, related to a particular training plan.

FIELD	DATA TYPE	NOTE	DESCRIPTION
nomPla	VARCHAR(25)	PK	Plan name
Nom Programa	VARCHAR(25)	PK FK (Programa Entrenament)	Training program name associated to this plan
identificador	VARCHAR(25)	PK FK (Programa Entrenamen)	User identifier of the training program associated to this plan
activitat	VARCHAR(25)	NOT NULL FK (Activitats)	Activity name of this plan
durada	TIME		Plan duration
distancia	UNSIGNED DECIMAL		Plan distance (expressed in meter)
notes	TEXT		Plan notes

USUARI

This table allows to save user information.

FIELD	DATA TYPE	NOTE	DESCRIPTION
identificador	VARCHAR(25)	PK	User identifier
Password	VARCHAR(25)		User password
anyNaixement	YEAR		User date of birth
Pes	UNSIGNED DECIMAL(3,2)		User weight (expressed in Kg)
Fumador	BOOLEAN		It states if the user is a smoker or not
Sexe	BOOLEAN		User Sex (TRUE = female, FALSE = male)
nivellActivitat	UNSIGNED INT(2)		User activity level
minHRrepos	UNSIGNED INT(3)		Minimum user rest Heart Frequency (expressed in beat per minute)
maxHR	UNSIGNED INT(3)		Maximum user Heart Frequency (expressed in beat per minute)
Alcada	UNSIGNED INT(3)		User height (cm)

Appendix B

Code examples

B.1 XML file

```
<?xml version="1.0" encoding="iso-8859-1" ?>
- <entrenament xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
- <atleta>
- <dadesPersonals>
  <MAXVENTILATION>145.147430298851</MAXVENTILATION>
  <MAXOXYGENCONSUMPTION>44.2072981678076</MAXOXYGENCONSUMPTION>
  <MAXBREATHINGFREQUENCY>52.9097930253813</MAXBREATHINGFREQUENCY>
  <PERSONAL_YEAROFBIRTH>1983</PERSONAL_YEAROFBIRTH>
  <PERSONAL_LENGTH>168</PERSONAL_LENGTH>
  <PERSONAL_WEIGHT>70</PERSONAL_WEIGHT>
  <PERSONAL_SMOKING>0</PERSONAL_SMOKING>
  <PERSONAL_GENDER>1</PERSONAL_GENDER>
  <PERSONAL_RESTINGHR>55</PERSONAL_RESTINGHR>
  <PERSONAL_MAXHR>199</PERSONAL_MAXHR>
  <PERSONAL_ACTIVITYCLASS>7</PERSONAL_ACTIVITYCLASS>
  <PERSONAL_MAXOXYGENCONSUMPTION>15</PERSONAL_MAXOXYGENCONSUMPTION>
  <PERSONAL_MAXBREATHFREQUENCY>55</PERSONAL_MAXBREATHFREQUENCY>
  <PERSONAL_LUNGVOLUME>6</PERSONAL_LUNGVOLUME>
  <PERSONAL_MAXVENTILATION>163</PERSONAL_MAXVENTILATION>
  <PERSONAL_EPOCLEVEL1>21</PERSONAL_EPOCLEVEL1>
```

```
  <PERSONAL_EPOCLEVEL2>63</PERSONAL_EPOCLEVEL2>
  <PERSONAL_EPOCLEVEL3>144</PERSONAL_EPOCLEVEL3>
  <PERSONAL_EPOCLEVEL4>228</PERSONAL_EPOCLEVEL4>
  <MOD_RESTHR>0</MOD_RESTHR>
  <MOD_WEIGHT>0</MOD_WEIGHT>
  <LOGTYPE>7</LOGTYPE>
  </dadesPersonals>
- <IntervalsHR>
- <intervalHR>
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  <minHRinterval>150</minHRinterval>
  <maxHRinterval>170</maxHRinterval>
  </intervalHR>
  </IntervalsHR>
  </atleta>
- <dadesEntrenament>
- <voltes>
- <dadesVolta>
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  <tempsIniciVolta>17:41.22</tempsIniciVolta>
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  <lapType>3</lapType>
  <notes>"</notes>
- <altitudVolta>
  <minima>-49</minima>
  <maxima>-29</maxima>
- <ascendentVolta>
  <temps>00:00:00</temps>
  <distancia>3</distancia>
  </ascendentVolta>
- <descendentVolta>
  <temps>00:00:00</temps>
  <distancia>12</distancia>
  </descendentVolta>
- <plaVolta>
```

```
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  </plaVolta>
  </altitudVolta>
- <velocitatVolta>
  <minima>0</minima>
  <maxima>4.07380727618375</maxima>
  <mitja>3.70833333333333</mitja>
  </velocitatVolta>
  <distancia>9310</distancia>
- <frequenciaCardiaca>
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  <minima>0</minima>
  <mitjana>155</mitjana>
  <PEAKEPOC>162.370833608398</PEAKEPOC>
- <Intervals>
- <interval>
  <id>1</id>
  <tempsSotaInterval>00:03:16</tempsSotaInterval>
  <tempsSobreInterval>00:00:08</tempsSobreInterval>
  <tempsInterval>00:42:34</tempsInterval>
  </interval>
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  <kilocalories>603.732716039904</kilocalories>
  </dadesVolta>
  </voltes>
  <tipusExercici>correr</tipusExercici>
- <dataEntrenament>
  <data>07.03.2006</data>
  <tempsInici>17:29.22</tempsInici>
  <tempsFi>18:15.18,2</tempsFi>
  </dataEntrenament>
- <unitats>
  <velocitat>min/km</velocitat>
```

```
  <altura>m</altura>
  <distancia>m</distancia>
  <temps>hora:min:seg</temps>
  <data>dia-mes-any</data>
  <pressio>pascals</pressio>
  <temperatura>centigrads</temperatura>
  </unitats>
- <dadesAtmosferiques>
  <pressioAire>0</pressioAire>
  <temperatura>0</temperatura>
  </dadesAtmosferiques>
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  <maxima>-29</maxima>
- <ascendent>
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  </ascendent>
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  </descendent>
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  </pla>
  </altitud>
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  <maxima>4.07380727618375</maxima>
  <mitja>3.38</mitja>
  </velocitatLog>
  <distancia>9310</distancia>
```

```
- <frequenciaCardiacaLog>
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- <IntervalsLog>
- <intervalLog>
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  <tempsSotaInterval>00:03:16</tempsSotaInterval>
  <tempsSobreInterval>00:00:08</tempsSobreInterval>
  <tempsInterval>00:42:34</tempsInterval>
  </intervalLog>
  </IntervalsLog>
  </frequenciaCardiacaLog>
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  </dadesEntrenament>
- <dadesEntrenamentHR>
- <dada>
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  <epoc>0.00831607204232823</epoc>
  <fc>109</fc>
  <peapok>0.00831607204232823</peapok>
  <rr>28</rr>
  <ventilacio>46.647539620774</ventilacio>
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  <RR>2.55752239436743</RR>
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  </dada>
  </dadesEntrenamentHR>
- <origenDades>
- <pulsometre>
  <marca>SUUNTO</marca>
  <model>T6</model>
```

```
  <fitxer>CorredorCollserola.sdf</fitxer>
  </pulsometre>
- <cartografia>
  <format>IDRISI32</format>
- <mdt>
  <codificacio>raster</codificacio>
  <fitxer>Cursa_Collserola</fitxer>
  </mdt>
- <capes>
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  </capes>
  <wrl>Cursa_Collserola</wrl>
  </cartografia>
  </origenDades>
  </entrenament>
```

B.2 Database access

```
//return vector of vector<float> with parameters
vector<vector<float>> GestorDisc::dataVectorSpeedDistance
(string idLog, string idU)
{
	std::vector<vector<float>> VelyEne;
	try {
	mysqlpp::Query consulta = connexio->query();
	consulta << "SELECT velocitatMitjana, distancia  FROM
	infoassociada  WHERE idLog = \"" + idLog +
	"\" AND identificadorUsuari = \"" + idU + "\"";
	mysqlpp::ResUse resultat = consulta.use();
	if(resultat) {
		mysqlpp::Row row;
		std::vector<float> vect_aux(2);
		while (row = resultat.fetch_row()) {
			vect_aux.at(0) = row["velocitatMitjana"];
			vect_aux.at(1) = row["distancia"];
			VelyEne.push_back(vect_aux);
			}
	}
	else
		throw "Error";

	return VelyEne;
	}
	catch(const mysqlpp::Exception& error) {
		//delete VelyEne;
		throw error.what();
	}
}
```

B.3 R connection

```
void RgraphSpeedEnergy::showSpeedvsEnergy()
{
  //show descriptive statistics about speed
  //average
  CEdit* edBx = (CEdit*) GetDlgItem(IDC_EDIT1);
  edBx->SetWindowText(floatToString(vecstat1.at(0)).c_str());
  //max
  edBx = (CEdit*) GetDlgItem(IDC_EDIT2);
  edBx->SetWindowText(floatToString(vecstat1.at(1)).c_str());
  //min
  edBx = (CEdit*) GetDlgItem(IDC_EDIT3);
  edBx->SetWindowText(floatToString(vecstat1.at(2)).c_str());

  //show descriptive statistics about energy
  //average
  edBx = (CEdit*) GetDlgItem(IDC_EDIT4);
  edBx->SetWindowText(floatToString(vecstat2.at(0)).c_str());
  //max
  edBx = (CEdit*) GetDlgItem(IDC_EDIT5);
  edBx->SetWindowText(floatToString(vecstat2.at(1)).c_str());
  //min
  edBx = (CEdit*) GetDlgItem(IDC_EDIT6);
  edBx->SetWindowText(floatToString(vecstat2.at(2)).c_str());


  //SpeedvsEnergy identifier
  flag=0;

  IStatConnector lConnector;
  IDispatch* lCharDev = NULL;
  IDispatch* lGfxDev = NULL;

  //check
```

```
if(FAILED(m_Char_dev.GetControlUnknown()->
  QueryInterface(IID_IDispatch,(LPVOID*) &lCharDev))) {
  MessageBox("Error from Character Device");
  return;
}
if(FAILED(lConnector.CreateDispatch
  (_T("StatConnectorSrv.StatConnector")))) {
  MessageBox("Error creating StatConnectorSrv");
  return;
}
//R initialization
lConnector.Init(_T("R"));

//declaration: symbol
VARIANT lVal1,lVal2;
VariantInit(&lVal1);
VariantInit(&lVal2);

V_VT(&lVal1) = VT_R8;
V_VT(&lVal2) = VT_R8;

//declaration: SAFEARRAY
VARIANT *pVarx;    // variant used to hold the vector x
VARIANT *pVary;    // variant used to hold the vector y

// CComSafeArray is an ATL wrapper for SAFEARRAYs, and are
//used simply to allow easy access to SAFEARRAY elements:
CComSafeArray<double> *pComArrX; // to hold vector x
CComSafeArray<double> *pComArrY;  // to hold vector y

// to specify bounds of a SAFEARRAY
CComSafeArrayBound bounds[1];
bounds[0].SetLowerBound(0);
bounds[0].SetCount(vectorLength);
```

```
// A helper for accessing CComSafeArrays by index
  LONG ix;

  pVarx = new VARIANT;
  pVary = new VARIANT;
  VariantInit(pVarx);
  VariantInit(pVary);
  // input is SAFEARRAY of doubles
  pVarx->vt = VT_ARRAY | VT_R8;
  // output is SAFEARRAY of doubles
  pVary->vt = VT_ARRAY | VT_R8;
  //set activeX TEXT OUTPUT
  lConnector.SetCharacterOutputDevice(lCharDev);
  //set activeX Graphic OUTPUT
  lConnector.AddGraphicsDevice(_T("Gfx"),m_Graph_dev.GetGFX());


  //Create the input SAFEARRAY and fill it with values:
  // now wraps a SAFEARRAY
  pComArrX = new CComSafeArray<double>(bounds, 1);
  // now wraps a  SAFEARRAY
  pComArrY = new CComSafeArray<double>(bounds, 1);

  for(ix = 0;ix<vectorLength;ix++)
  {
         pComArrX->SetAt(ix,vc1.at(ix),1);
         pComArrY->SetAt(ix,vc2.at(ix),1);
  }

  //point the input VARIANT at the array
  pVarx->parray = pComArrX->Detach();
  pVary->parray = pComArrY->Detach();

  //ready to call R!
  lConnector.SetSymbol("Speed", (*pVarx));
```

```
  lConnector.SetSymbol("Energy", (*pVary));

  //regress x on y and store the results
  lConnector.EvaluateNoReturn(_T("result <- lm(Speed ~ Energy)"));
  //PLOT
  lConnector.EvaluateNoReturn(_T("plot(Speed, Energy, col=4,
  main=\"Speed vs. Energy\")"));
  //add regression line
  if (vectorLength>1)
       {
       lConnector.EvaluateNoReturn(_T("abline(result, col=2)"));
       //save into a sting vector which contains the output
       lConnector.EvaluateNoReturn
       (_T("string_vector<-capture.output(summary(result))"));
       //print this vector
       lConnector.EvaluateNoReturn
        (_T("cat(string_vector,sep=\"\n\")"));
       }
   //close and release resources
  lConnector.ReleaseDispatch();
  lConnector.RemoveGraphicsDevice(_T("Gfx"));
  lConnector.Close();
}
```

Appendix C

Work planning

Activity planning has a great importance to obtain a good work organization. For this reason, it is necessary to make up a Gantt chart that summarizes into an intuitive and a schematic way the whole activity set. By its observation, it is very simple to understand which are the steps that have been followed to achieve the conclusion of this project work. An important thing to remember is that the Gantt chart shows the follows activity and it does not have to be confused with the project design.

The present project has been organized as it is shown by the gantt chart (C).

REVIEW phase is the first step of the thesis and it is composed by:

- **review existing system:** a panoramic view of the entire project, why and how it has been created. To learn technical terms, parameters and concepts about athletics is necessary to establish the athlete's performance. To learn its potentiality and, looking the program code, understand how handle it and how make future modifications.

- **Identify user requirements:** watching the whole system, understand its functioning and its faults, related on the project's objective. These last ones are very important because they signal which parts have to be developed.

- **Identify work:** identify work already done and, according with the user requirements, identify where improvements are needed. Choose which improvements will be implemented.

- **Identify work specifications:** it means to understand which elements, data and information are interesting and useful to implement this work. Also deciding which data have to be extracting from the Database, which ones have to be processed and analyzed.

The main phase of the current work is clearly the *DEVELOPMENT* one. It is divided into:

- **Analysis of the algorithms:** starting from all parameters which are involved into the calculation of different kinds of statistics, this phase consists of the creation of algorithms to achieve these goals. More in detail, three algorithms have been studied and created to calculate exertion, gradient and bend statistics.

- **Program implementation:** this phase is concurrently with the analysis of the algorithms and the program test. It is the longest phase of the project, because it consists of programming the new planned functionalities, using the Visual Studio 2005 framework. The used programming language is C++.

- **Program tests:** they have been done very often because are a good index of the work quality. Especially testing all possible scenarios and boundary cases, in which one can find the major number of bugs.

- **Software integration:** integration of this work with the existing project. Particular attention to menu integration to obtain a more user-friendly interface. It also include a setup project creation for an easy software installation.

- **Final modification:** in this phase, little details have to be changed or improved to improve the work's quality.

- **Final tests:** the lasts general controls to be sure that the whole software works correctly.

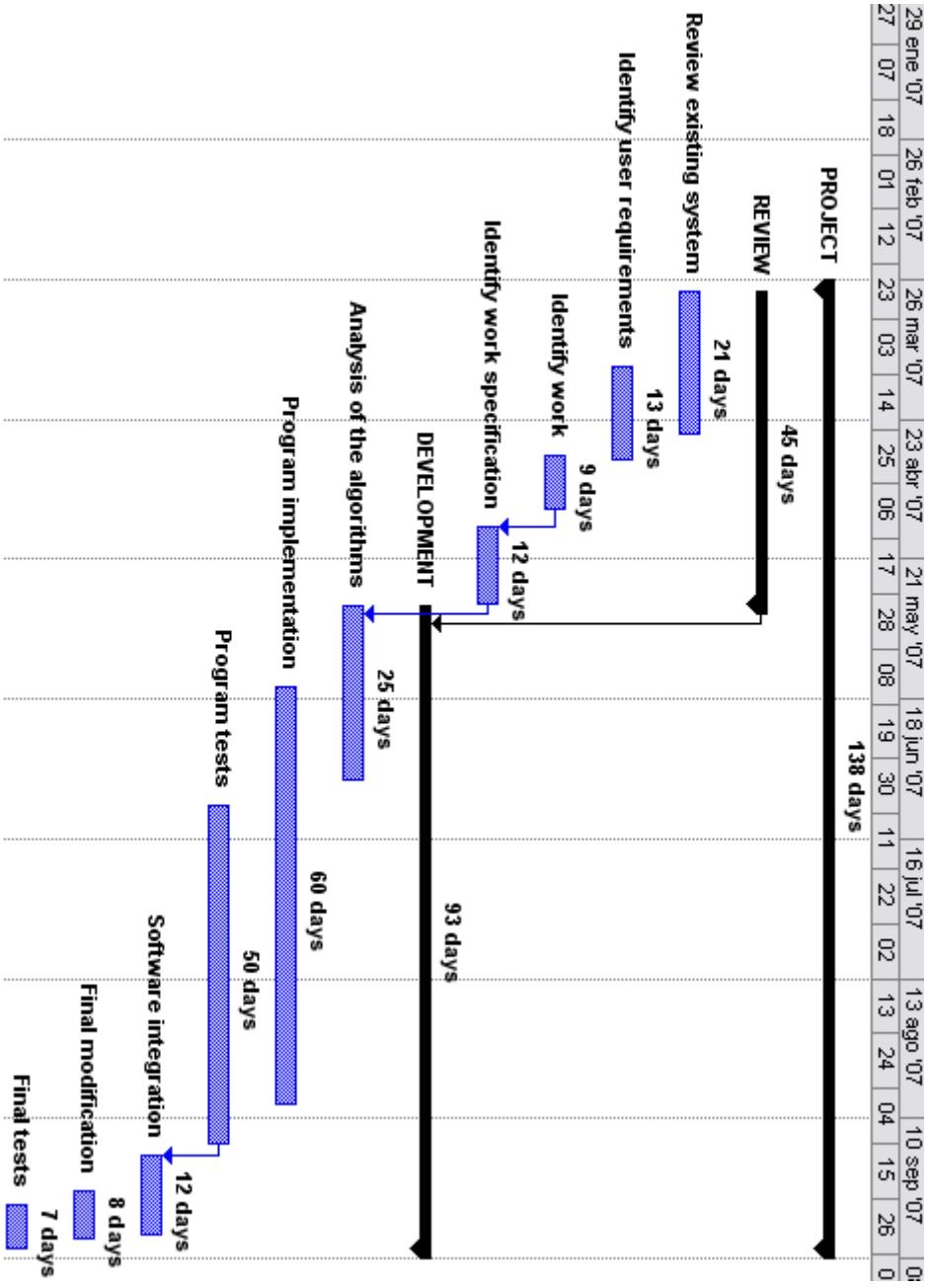

Figure C.1. Gantt chart

The just described activities that compose the whole project work, are organized into more sub-tasks. The following table describes the work organization and shows the related working hours, considering that some tasks are partially overlapped and a mean working day of 6 hours:

ACTIVITY	TASK	SUB-TASK	Hr
REVIEW	Review existing system	Previous related thesis study	18
		Athletics and related technical terms study	6
		Existing commercial products study (Polar, Suunto and Garmin)	18
		Atleta+ capabilities study	12
		Atleta+ fault and improvement study	6
		XML study	6
		Software development product (Microsoft Visual Studio 2005) study	6
		Atleta+ project code organization study	36
		Statistical software capabilities study (R)	6
	Identify user requirements		30
	Identify work		54
	Identify work specifications		72
DEVELOPMENT	Analysis of the algorithms	Statistical software work study (R)	6
		Exertion's parameters study and algorithm creation	30
		Gradient's parameters study and algorithm creation	60
		Bend's parameters study and algorithm creation	30
	Program implementation	Statistical software connectivity study (R-COM)	30
		Database connectivity study (MySQL++ classes)	12
		ActiveX study	6
		C++ programming	210
	Program tests		90
	Software integration	Visual Studio Setup Project study	12
		Setup project implementation	12
	Final modifications		30
	Final tests		30
		TOTAL	828

Finally, it is necessary to do a cost analysis. Project costs includes two points:

- *programmer cost*, calculated in terms of working hours. As can be seen from the previous table, the spent hours in the project are 828. Considering a medium programmer cost of 20 €/hour the total programmer cost is:

PROGRAMMER	COST [€/h]	HOURS	TOTAL [€]
Gianfranco Arcai	20	828	16560

- *Software license cost*, depending on the commercial costs are:

SOFTWARE	USE	COST [€]
Visual Studio 2005 professional edition	Development	1200
R	Statistical analysis	0
MySQL	Database	0
Latex	Editing	0

The total cost of the current project is the sum of the programmer and the licenses costs, and it amounts to **17760 €**.

Appendix D

Glossary

EPOC

Excess Post-exercise Oxygen Consumption, it is a measure for the amount of oxygen that the body needs to recover from physical exertion. It describes the accumulating training load. It is a measurably increased rate of oxygen intake following strenuous activity. The extra oxygen is used in the processes that restore the body to a rest state and adapt it to the just performed exercise.

HR

A measurement of the heart rate, most commonly expressed as the number of beats per minute (bpm).

KILOCALORIE

A measure of the energy value in physical activity.

1 kilocalorie (kcal) = 1 Calorie (Cal) = 1000 calories (cal)

RESTING HEART RATE (HR_{REST})

The lowest number of heartbeats per minute (bpm) at complete rest. HR_{REST} decreases as the fitness level increases. A typical value for adults is 60-80 bpm, but for top athletes it can be below 30 bpm.

RR INTERVAL

It is the inter-beat interval.

TARGET ZONE

To reach the goal by defining the right intensity for each exercise. Depending on the product, it is possible to define the target zone based on heart rate, speed/pace or cadence.

VENTILATION

Also called *ventilation rate*, it is the rate at which gas enters or leaves the lungs.

VO2

The maximum capacity for oxygen consumption by the body during maximum exertion per minute. Also known as aerobic power or maximal oxygen consumption. VO_{2max} is a commonly used determinant of aerobic (cardiovascular) fitness. The most accurate way to measure the VO2max is to perform a maximal exercise stress test in a laboratory. VO_{2max} is expressed in $[ml \cdot kg^{-1} \cdot min^{-1}]$.

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