Chapter 1

Introduction

1.0 Overview

This chapter is an introductory one, expressing my research motivation and aim. It outlines the content of subsequent chapters, and reveals my major research contributions and achievements

1.1 Research Motivation and Aim

This research aims to explore computer-based technology support for the financial industry. My research interest stems from my awareness of the importance of the role played by finance in the prospect of humans and nations and the role of computer-based technology as a driving force in all business sectors including the financial one. Computer-based technology is becoming an integral part of our life, and its potential use in supporting our cognitive and routine activities is of critical importance. It is impossible to ignore the role for computer-based technology in our daily activity, but choosing an appropriate technology solution is a challenging task.

The financial industry is witnessing major changes manifested in the introduction of new financial instruments, major structural changes in the financial markets, increasing financial markets integration, and new roles for market participants [Lan99, Ode00, RB00]. Computer-based technology has a central role in motivating interest in change and suggesting paradigms for its application [FRKBCJ00, Dav93, Dav96]. This thesis identifies some key issues for the use and application of computer-based technology in the financial industry at the institutional, market, and investment levels. The following paragraphs elaborate on these issues at these three levels.

Key issues of the application of computer-based technology in finance

At the ***institutional level***, computer-based technology plays an important role in leading the structural institutional change to gain competitive advantages in a global market [Dav93]. *Software integration* [BM99], and *virtual collaboration* emerge as key concerns in the financial enterprise.

At the ***market level***, computer-based technology plays an important role in *supporting the shift from an old to a new trading model* [Lan99]. The old trading model depends on a physical place, a central role for financial inter-mediation, and limited geographical spread of trading activity. In the new trading model, an appropriate use of computer-based technology aims at delivering straight through processing (STP), facilitating cross border trading, supporting market integration, reshaping the role of different market participants, re-engineering financial trading systems, and providing intelligent management and delivery of trade information, reporting, and investment services.

At the ***investment level***, *financial engineering*, and *the finance research development cycle* are increasingly relying on computer-based technology and the power of the computer to support intelligent human activity.

Challenges facing the application of computer-based technology in finance

Acknowledging the significant role of computer-based technology in the advance of the financial industry is important, but recognizing its limitations in delivering the intended support is essential in order to overcome these limitations and achieve the targeted goals.

Major challenges are faced in the application of computer-based technology in the financial industry. This thesis identifies the key problem in meeting these challenges as finding a suitable framework for software system development (SSD) for modern finance.

It is convenient to view software system development in finance as represented by two cultures:

(1) a traditional culture[1] that relies on orthodox techniques that frame the software system development into rigid stages. These approaches to SSD typically rely on predefining and fixing a boundary for the software system to be developed, there is an increasing awareness of the need for a more flexible boundary that can grow as the development proceeds[2];

(2) an emerging culture that involves "ad hoc" uses of spreadsheet, databases, virtual reality VR, artificial intelligence, multi-media, etc.

The emerging culture in which advanced databases, spreadsheet, virtual reality, multi-media, and artificial intelligence are getting applied is quite different from the classical computing culture with its strong mathematical and logical foundations. There are potential benefits in finding a suitable framework for studying both the traditional and the emerging computing culture to SSD in diverse domains, including finance. This is particularly relevant because of the prominence of mathematical and statistical models in the finance domain and the importance of unifying the logical / mathematical with the informal experiential aspects. More generally, there is a related need for SSD principles that help to integrate automated processes with activities directed by human judgement, discretion, and observation of the world. In this respect, traditional SSD is not well suited to the demands of modern finance.

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[1] This refers to method-based approaches to software system development including traditional waterfall methods [SS95, STM95], object-oriented methods [Boo94, CY90, JCJO92]. Method based approaches to software system development provides formally-defined methods, techniques and tools that can in principle guide the development of software systems in a systematic and cost-effective fashion.

Moreover, whilst the concepts and techniques of the emerging culture helps to address various aspects of the new SSD agenda, there is arguably no satisfactory foundational framework[3] within which to gain a holistic view. Indeed, the impact of new technologies and techniques has to some extent been a negative one, compounding the problem of integration by extending the catalogue of disparate technologies. This motivates our interest in a paradigm shift in SSD practices for the finance domain.

Motivation for EM

Empirical Modelling (EM) technology (a suite of principles, tools, techniques, and notations) aims to achieve greater integration of the human and computational activity by adopting novel software system development practices[4]. Its key concepts are agency, dependency, and observation. To some degree, these concepts are represented in current SSD practices – for instance in agent-based systems, observer-like objects in object oriented development and spreadsheets, but the way in which they are deployed in EM is distinctive, and invests them with an ontological status that is quite unlike that associated with classical models of computation. EM involves situated activity in which the roles of the modeller, the artefact, and the situation are inseparably linked, and leads to the construction of computer-based artefacts that stand in a special relation to the modeller's understanding and to the situation to which they refer.

EM technology emphasizes the importance of a broad foundation for computing capable of embracing, when possible, disparate technologies in an open development environment. Throughout its evolution Empirical Modelling technology has shifted focus from programming an application to modelling a domain. EM technology provides a modelling framework that precedes Object Oriented Modelling in identifying entities and their reliable patterns of behaviour suitable for object and corresponding methods abstraction [BJ94]. It proposes new foundations for artificial intelligence that take into account experiential knowledge in developing computer-based artefacts [Bey99]. It promises support to VR technology at the analysis and design level to take into account the social aspect of a virtually mediated environment [MBG01]. It provides a framework that complements formal representation and rigid symbol based modelling with experience based modelling favouring semi automated activities [BRR00-1, BRR00-2, CRB00].

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[2] For instance, there are several approaches that regard software system development as a 'situated' activity in the sense used by [Suc87] and that aim at reconciling the social and technical aspect in software system development [Fit96, Gog94, HKL95, HKN91, Flo95, CS90, Mum95, AF95, Sun99].

[3] Though proposals such as Checkland's Soft System Methodology (SSM) [CS90] and other systems theory approaches are in this spirit.

The thinking behind Empirical Modelling Technology stands in a particularly interesting relation to critiques of traditional empirical approaches[5], both from a philosophical perspective, and as they apply to computer science topics such as software engineering and AI. These include: the philosophical stance of Radical Empiricism[6] of William James, the views of Fred Brooks on Software engineering theory and practice[7], Kirsh's critique of the logicist[8] approach in Artificial Intelligence, and the founder[9]'s view on establishing a new computational framework capable, when possible[10], of embracing disparate principles, theories, and foundations.

Empirical Modelling technology motivates a new software culture [Sun99, Bey01] that potentially supports a stronger relationship between computer-based technology and various activities in social application domains. In particular, it addresses the following fundamental issues of SSD identified in [Sun99]:

(1) SSD is a human activity that needs technical support in order to enhance its application to social domains;

(2) SSD is highly associated with its context, which must be considered in a situated manner;

(3) human agents are the most important dimension in SSD;

(4) interpersonal interaction is the most crucial activity in SSD; computer-based support plays an enabling role in facilitating human agency and promoting interpersonal interaction.

The essential character of SSD in EM suggests a clear distinction between SSD in EM and traditional SSD. The latter is a process framed into rigid stages, a closed boundary system, and a preconceived functionality for an end product to be delivered at the end of the SSD process. On the contrary SSD in EM consists of a collection of situated activities that arise in the construction and use of the required system in the real world. This situated activity takes into account both technical and social aspects and directs a central focus on the interaction

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[4] Refer to amethodological SSD proposed in [Sun99].

[5] As characterized by the relationship between what is interpreted as "given by theory" and "given by observation" in an experimental context.

[6] It is characteristic of Radical Empiricism that relationships in the world, that are traditionally attributed to theory, are interpreted as empirically given.

[7] There is no "silver bullet": no single software engineering methodology that can deliver a complete solution to complex problems in the real world domain.

[8] This is as characterized by the physical symbol system hypothesis introduced by Newell and Simon (1976).

[9] The founder of the Empirical Modelling project is Meurig Beynon.

[10] In discussing Empirical Modelling as a new foundation of artificial intelligence, Beynon (1999-2), argues that there is no possibility of merging the logicist and non-logicist approaches in artificial intelligence.

between human agents involved in the SSD activity and the product-under-development. This product under development is represented by a computer-based model that reflects an evolving software system with dynamic rather than rigid boundaries. Deriving useful systems from an EM approach to SSD necessitates an appropriate circumscription of the model once a desired functionality can be relied upon.

The principal claim of the thesis

The principal claim of the thesis is that EM technology promises to offer computer-based support to software system development (SSD) that is better adapted for the financial industry at the institutional, market, and investment level. EM can potentially help to address the need of finance in the following ways:

At the institutional level, by establishing principles and foundations for software system development meeting integration and virtual collaboration needs.

At the financial market level,

(1) by providing computer-based support to software system development adapted to the needs of the new trading model;

(2) by establishing principles that support qualitatively different trading patterns by accounting for different factors including: a richer set of observables shaping and being shaped by the trading environment, different modes of interaction and behaviour of market participants, and different insights for strategic decision making;

(3) by observing the virtual trading activity from different perspectives (technical, social, and human).

In investment research and analysis,

(1) by enabling a more intimate relationship between the software system development activity and the finance research development activity;

(2) by supporting distributed modelling in software system development for financial engineering.

Strategy for supporting the claims

Empirical Modelling technology draws on well established principles, techniques, and tools that introduce a radical shift in perspective in software system development practices. We will argue that EM has strategic implications of relevance to finance because (in principle) it:

a) supports an open, human centred, amethodological, context-dependent, situated, and user-centred approach to software system development

With the complexity and continuous change in the financial industry, adopting rigid approaches to software system developments might fail to cope with the change and incur the financial industry enormous re-engineering costs. An EM approach to software system development provides greater flexibility and adaptability to change.

b) *maintains a semantic relationship between the computer-based artefact and its real world referent*

In modelling an application domain, EM technology establishes a semantic relationship between the computer-based aretefact and its real world referent. This motivates a re-thinking of the software system development cycle, the requirement engineering phase in software system development, and the system's boundary.

c) supports experiential knowledge construction in software system development

The finance literature reveals conflicting approaches and theories (e.g. Arbitrage Pricing Theory (APT) vs the Capital Asset Pricing Model; Fundamental vs Chartist financial analysis, the random walk and Efficient Market Hypothesis vs forecasting future price indicators based on past indicators; etc). This motivates experiential knowledge construction in software system development for the finance domain, and is supported by Bryan's view on mathematical financial modelling:

" *Financial modelling*[11] *is emphatically not an academic process, and past experience has shown elegant mathematics and sophisticated programming as more likely to lead to failure rather than forming a pathway to success. The importance of models being developed in close conjunction with (if not by) the user cannot be over-emphasised*" [Bry82].

d) supports interpersonal communication in software system development

Group social activity is central at all finance levels (financial enterprises, markets, and investment). Financial markets can be viewed as a social network grouping different market participants (brokers, dealers, investors, specialists, etc..). The financial enterprise is a social network comprising top management, regulatory and supervisory authorities, and operational entities. The financial analysis and investment activity is a group activity involving a network of academic researchers and practitioners. This motivates greater account for the group social activity in software system development for the finance context. Interpersonal interaction in

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[11] Financial modelling is the process of creating a *picture* or *financial model* of a financial scenario, where the model represents a simplification of the real situation [Bry82]. Financial models can be of two types: analogue models (physical representation of objects or situation that does not actually look like the real thing, examples include diagrams and charts), or mathematical models (models composed

the software system development activity for finance and in collaborative group work activity related to finance poses great challenges to emerging communication-based technologies such as the internet. This is mainly due to the complexity of interpersonal interaction and the difficulty of providing it with the appropriate computer-based support [Son93]. EM proposes a computer-based support for interpersonal communication that takes into account various modes of interaction and the role of agency in communication, and relies on the communication of definitive scripts as a medium for sharing artefacts and insight.

e) supports software system development with explanatory modelling of application domains

Traditionally, mathematical models and natural language have been used to represent structured knowledge of the finance domain. Financial trading is an example of a context where mathematical abstraction may fail to convey the behaviour of different trading parties, trading signals, and trading systems. There is a rising need for the investigation of new principles to supplement traditional mathematical modelling in modelling complex trading environments. The ability to forecast the impact of a new technology or structural change prior to its introduction, and to investigate an optimal financial market structure and organization, need more than traditional financial modelling techniques and call for cognitive and experience based modelling. In this connection, business process modelling, business process re-engineering, and analysis of virtual social trading networks are important considerations.

f) motivates new relationships between the software system development activity and diverse real world activities that are not inherently computer-based

By considering the situated nature of the software system development activity new relationships between SSD and various activities in social application domains emerge. Examples are relationships between the finance research development activity and the SSD, and business process modelling and software system development.

Implications a) through f) are wide-ranging and are not specific to financial applications. The EM tools are not sufficiently mature to allow us to demonstrate these implications in practical applications in finance at present, especially on the scale that is appropriate in industrial case studies. Previous case studies using EM tools do, however, supply proof-of-concept evidence

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of symbols and mathematical relationships that represent a real situation). Financial models can be also classified by the way they are used, such as for simulation, optimisation, or forecasting [Hon99].

in relation to a) through f). On this basis, the thesis makes it plausible that EM can deliver a) through f) by:

1) discussing the wider agenda of computational activity in addressing the technical and strategic demands of the applications of computer-based technology in finance: this involves identifying these demands and exposing the challenges current technologies face in meeting them. It also motivates a paradigm shift at the computational level (cf. chapter 2).
2) introducing EM technology as a suite of principles, techniques, notations and tools with particular reference to simple case studies drawn from the finance domain. The chosen models enable us to discuss the significance of agency, dependency and observables in relation to particular financial applications (cf. chapter 3).

3) highlighting the distinctive qualities of model building in EM that motivate a paradigm shift at the computational level (cf. chapter 3). These qualities include:
   - the focus on state as experienced
   - knowledge construction using an artefact
   - the support of collaborative relationships in distributed modelling
4) reviewing the broad implications of EM for software system development meeting the wider agenda for computational activity: This involves the analysis of relevant history of EM, in particular with reference to previously developed models that demonstrate the potential broader implications of adopting an EM paradigm (cf. chapter 4). The case studies considered are:
   - A *railway accident model* that demonstrates knowledge re-construction of a historical event in a distributed environment that reveals the complexity of social communication and the different possible construals of a historical event.
   - A *virtual electronic laboratory model* that demonstrates the complexity of the technical support needed for group social interaction and highlights the situated nature of this interaction.
   - An *attribute explorer* that supports the visual amethodological exploration of data sets. This exploration helps in identifying complex patterns of relationships between data sets.
   - A *timetabling model* that illustrates a novel mode of decision support that allows close integration between manual and automated activity.

5) by developing proof-of-concept models that illustrate how EM might eventually deliver new solutions to problems in the finance domain different in character from solutions delivered by existing computer-based support. Relevant issues to be examined include:
   - *Software system development* in the financial enterprise with particular emphasis on integration and virtual collaboration (cf. chapter 5).
   - *Software system development* for the financial market with particular reference to open and explanatory modelling activity and the use of artefacts to construe complex application domains (cf. chapter 6).
   - Distributed modelling in *software system development* for financial engineering (cf. chapter 7).
   - The relationships between the *software system development* activity and the finance research development activity (cf. chapter 8).

The above issues 1) .. 5) are considered in the referenced chapters. The outline of each of these chapters follows.

1.2 Thesis Outline

The principal aim of this thesis is to investigate the application of an experience based technology, "Empirical Modelling (EM)" technology, to the finance domain. The research is framed within a web based environment[12]. Several case studies from finance are considered, these include: software integration and virtual collaboration in the financial enterprise, building virtual environments for financial trading, computer-based support for financial engineering, and computer-based support for a typical finance research development cycle.
The rest of the thesis consists of eight chapters that are organized as follows:

Chapter 2 frames key issues for the application of computer-based technology in finance. It argues that finance makes technical and strategic demands on computing that pose great challenges to current tools and technologies. This leads us to the identification of a "wider agenda for computing" that motivates a paradigm shift at the computational level.

Chapter 3 introduces EM technology as a suite of key concepts, techniques, notations, and tools. It highlights the distinctive qualities of model building in EM that can potentially meet the technical demands of finance identified in chapter 2.

Chapter 4 discusses the broad implications of EM on the wider agenda of computing. It examines the nature of the paradigm shift in SSD associated with EM, and explores the implications for the strategic demands of finance identified in chapter 2. The latter are illustrated with reference to various previous case studies in EM. These case studies show in particular that EM can potentially lead to a closer integration between the software system development activity and activities in real world domains, a theme that is developed in the remainder of the thesis.

Chapter 5 considers the prospects for EM technology in the financial enterprise, and in particular proposes a new framework for software system development for integration and for virtual collaboration. Software integration and virtual collaboration are examples of two software development activities where people, devices, and programmable components should integrate more coherently to attain their objective. This entails viewing a system from many different perspectives, taking into account the social and the technical aspects as well as their coherent integration. Devising a solution meeting all requirements is hardly possible. The solution is situated in nature and grows with growing needs. The technical and social aspects of software integration are discussed with reference to a Situated Integration Model (SIM). The needs and requirements for integration are motivated with the example of the integration of ERP and e-commerce applications. In software system development for virtual collaboration, EM emphasizes the importance of considering human information behaviour (HIB) with reference to its associated context, situation and social network, as characterized by Sonnenwald in [Son99].

Chapter 6 proposes a new modelling approach for software system development for the financial market adapted to the new trading model. The proposed Open Financial Market Model (OFMM) is characterised by the openness of the modelling activity and its use for requirement engineering throughout the entire software system development. The technical implementation and practical application of the OFMM is considered with reference to a case

[12] This web-based environment includes relevant information and the technical work related to the models considered in each chapter as well as an electronic version of the thesis in Word and pdf

study that draws on various financial market applications and in particular the Monopoly Dealer simulation developed by Larry Harris[13]. The case study model is developed using EM and VR technology. The chapter proposes an EM – VR merge for a broader foundation of computing tackling the wider agenda for computing in finance.

Chapter 7 considers modelling interpersonal communication in software system development for financial engineering. This is motivated by the need to consider the wider view of the financial engineering activity undertaken within a social network of academics or practitioners. The case study considered is the spreadsheet affine interest rate model developed by Nick Webber. An extension of Webber's model has been developed using Distributed Empirical Modelling (DEM). This model can be interpreted in two ways: (1) as a proposal for distributing the spreadsheet financial engineering activity to suit a group learning environment and a social network of practitioners that are using a financial instrument model for various purposes; and (2) as exposing the need for, and requirements of, computer mediated interpersonal interaction for group financial engineering activity.

Chapter 8 studies SSD in relation to the finance research development cycle (FRDC), with reference to a practical academic case study. It proposes a situated account rather than an abstract account of the finance research development cycle (FRDC). The motivating case study for this chapter is a long horizon event study using UK financial data [Ho00, AH01] undertaken by Keng-Yu Ho[14]. The review of the technical computer support activity undertaken by the author in this case study enriches the understanding of the relationship between SSD and the FRDC and informs a brief analysis of the future prospects of EM technology for data intensive applications.

Chapter 9 concludes with a summary of the original contributions of this thesis to the fields of computer science and finance and endorses Sun's claim [Sun99] that software system development is most appropriately viewed and conducted as a context dependent social activity. The conclusion motivates further research and development activities for EM technology for finance, with the social and human aspects as central considerations in the technical analysis. Further research on various case studies considered in chapters 5 through 8 are suggested and an EM – VR merge is proposed.

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format.

[13] http://lharris.usc.edu/trading/DealerGame\Default.htm

1.3 Research Contribution

The original specific contributions in this thesis are briefly reviewed below with reference to the relevant chapter.

Chapter 2 identifies a wider agenda for computing in finance that motivates a paradigm shift at the computational level. Currently there is a wide gap in the literature covering computer-based application in finance. Attempts at bridging this gap are found in the literature on AI and its application to finance (see [Deb98, FK95, TL96, Deb94, Pro91]) and sparser literature describing the application of IT at the operational level in the financial enterprise (see [Ess93]), the implementation of trading strategies (see [Gol88]), and various statistical tools used in financial analysis (see [Vin00]). The novelty of the literature review presented in chapter 2 is in considering the wider need of the application of computer-based technology in finance at the three levels (enterprise, market, and investment).

Chapter 3 introduces EM with reference to simple but original case studies: Ordinary Least Square (OLS) regression, the capital asset pricing model (CAPM), the story of a retail trade in New York Stock Exchange, and a distributed stock market game. The OLS regression is implemented as a built-in feature in Excel and the CAPM model is implemented using an Excel spreadsheet by Peter Corvey (another similar implementation of the CAPM is in software accompanying the textbook by Elton (et al, 1995)). The novelty in the implementation of the OLS and CAPM using EM tools is in illustrating the potential of EM technology in generalizing the spreadsheet concept in three respects: presentation, underlying data type, and agency. Describing a retail trade process in the financial market using a special purpose notation such as the LSD notation that can serve in developing an interactive situation model for exploring this trading process is an innovation in modelling the financial trading process. The novelty is in combining the use of descriptive and interactive computer-based media to serve in experiential knowledge construction in connection with the financial trading process. The originality in considering the distributed stock market game is in leveraging enhanced communication by sharing definitive scripts.

Chapter 4 overviews the application of EM technology in various application domains with particular emphasis on establishing a closer integration between the software system development activity and diverse real world activities that are not inherently computer-based. A review of the use of EM technology in various application domains was presented in [Sun99] and [Car99]. The added value of the review conducted in this chapter is

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[14] a doctoral researcher at Warwick Business School

in the focus on the theme of establishing a closer integration between the computational and the real world activity. This theme is quite appropriate when applied in meeting the wider agenda of computing in finance, and reveals the importance of investigating the applications and prospect of EM in finance.

Chapter 5 illustrates the novel use of the EM approach in integrating the social and the technical in the financial enterprise with reference to software integration and virtual collaboration. The situated integration model (SIM) presented in this chapter is an original approach to software integration that exploits the more holistic view of the integration activity that EM affords. The EM approach to software integration was the subject of a joint paper with Meurig Beynon that appeared in the Fourth World Conference On Integrated Design and Process Technology, Incorporating IEEE International Conference on Systems Integration (1999) [BM99][15].

The application of EM principles to building virtual environments for collaboration was also the subject of a joint paper with Meurig Beynon that appeared in the Fifth World Conference On Integrated Design and Process Technology [BM00]. The use of EM principles in combination with the concept of Human Information Behaviour described in [Son99] in terms of context, situation and social network is an original approach for building virtual environments for collaboration proposed by the author.

Chapter 6 proposes the original idea of using an Open Financial Market Model (OFMM) for studying the shift from the old to the new trading model. This chapter features two original extensions of the Monopoly Dealer Simulation[16], using EM and VR technology with the aspiration to develop an OFMM. The application of EM and VR technology to financial trading appeared in the Human Computer Interaction International Conference proceeding (2001) [MBG01] and was the topic of a seminar I presented at Laboratoire de Robotique De Paris in France in April 2001.

The proposal of an EM-VR merge to establish a suitable framework for deploying EM and VR technology in modelling social applications in domains such as finance is an original idea of the author to be pursued in future research.

In ***chapter 7***, the original contribution is in re-engineering the affine interest rate model implemented on a spreadsheet by Nick Webber to take into account distributed modelling and computer-mediated interpersonal interaction at classroom level. The idea of viewing computer-based support for financial engineering as a social activity undertaken in a

[15] We have been invited to submit an extended version of this paper to the Journal of the Society of Integrated Design and Process Technology.

network of practitioners or academics is an original idea that was motivated in other literature such as [JES00].

Chapter 8 describes the Financial Research Development Cycle and its associated computer-based support in a novel way with reference to long-horizon event studies conducted by Keng-Yu Ho on financial data from the UK and USA markets. This financial study is pioneering, where research on UK market data is concerned, in its novelty and the wide ranging scope of its quantitative analysis [Ho00, AH01]. The author's novel contribution is in considering the needs and requirements of a closer integration of the software system development activity and the financial research development cycle (FRDC).

In general, my research contributes to two fields of study, computing and finance, which are becoming increasingly dependent on each other, with greater dependence of finance on the computational power and the evolution of communication technology. The combination of these two fields of study is sometimes referred to as computational finance. However, the use of this term is currently limited to the computer implementation of financial and econometric models using fourth generation languages and artificial intelligence tools.

Real world domains and computer-based environments are implicitly and explicitly linked through high-level concepts and low level techniques. Explicit links are supported by commonly available technologies, but implicit links[17] can only be explored and understood with stronger foundations for advanced human-centred technology. Activities conducted in the real world finance domain and in computer-based environments are linked through implicit high level shared concepts, and explicit low level common techniques. Current technologies are primarily aimed at supporting explicit links. Examples of this include encoding trading strategies, automating trading processes, managing information, etc. Mathematical abstraction, statistical analysis, and methodological approaches are favoured in establishing the explicit links. Implicit links are not always easy to detect and are difficult to support as they relate to ontological issues pertaining to the two domains (finance and computing).

The difficulty of identifying the implicit links between finance and computing is exacerbated by the historical legacies of the two disciplines, and the very radical transformations to which they have been subjected since they first came together.

These issues are not easily formulated in either domain. In earlier days, it was easy to define a computer environment as an electronic medium for processing information from input to

[16] Originally developed by Larry Harris

output. A single book on the computer science discipline could cover most of the issues relating to input-process-output activity, its requirements and techniques. With the computer and communication revolution and the wide penetration of internet technology into almost every daily activity, new uses for computer-based environments have emerged both incidentally, and driven by an incentive or strong need. Similarly, the financial industry is witnessing major structural changes that are re-defining the role of market participants and re-shaping core activities in the market. Implicit links are emerging as a cause and effect of change and the need to cope with change. Change is reshaping the boundary of different domains of study and the boundaries of divisions within the same domain. Technologies that are better positioned at explaining and coping with change can play a pioneering role in reinforcing emerging implicit links across different disciplines.

This thesis makes it plausible that there can be a very different relationship between computing and finance, that can be established through interdisciplinary collaboration that exposes and re-enforces the implicit, high level conceptual links and the explicit low level technical links that are respectively associated with the strategic and the technical demands for computing in finance to be identified in chapter 2 (cf. Figure 1.1). Specifically, the thesis reveals that novel software engineering practices, experience based modelling, and alternative programming paradigms in EM can impact on the finance domain at the market, enterprise and investment levels in both technical and strategic respects. In particular, the thesis shows that key concepts in EM (observables, agency, dependency), are well suited to framing key concerns of the application of IT in finance, and that a computer-based modelling paradigm based on these concepts is potentially very well oriented towards satisfying current and emerging demands in finance.

[17] By the term ‘implicit links” we refer to a common shift in perspective on change that is independently motivated by needs and developments in finance and in computing.

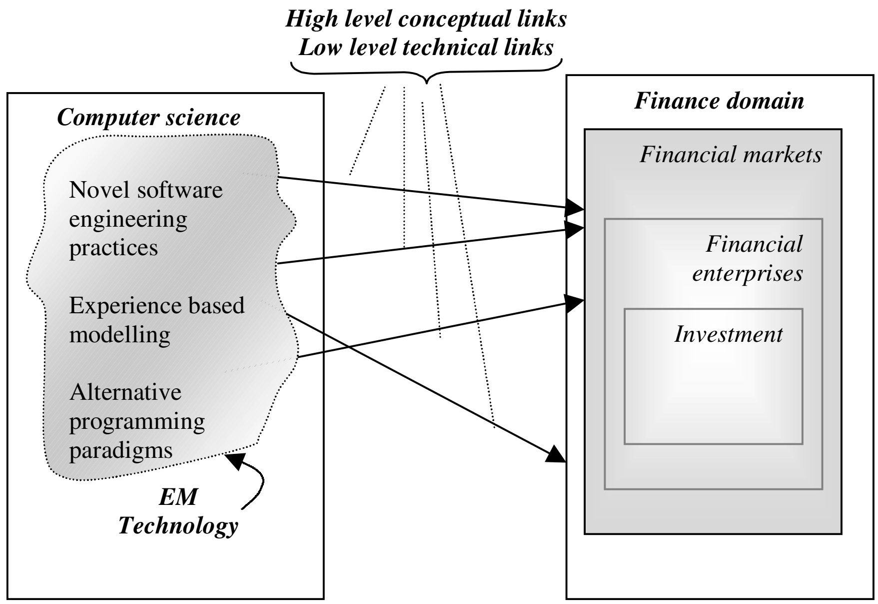

Figure 1.1 Emerging links across the two fields computer science and finance

The specific topic to which the thesis contributes understanding is "***Software System Development and Software Engineering in the Finance Context***". This thesis consolidates on previous EM research on software system development and software engineering [Sun99, BCSW99, SB98, Sun98]. Sun (1999) examined fundamental issues of software system development relating to its essential character, real-world context, human factors, and social factors. His findings were based on EM principles and foundations and supported by a deep investigation of distributed Empirical Modelling in software system development in both theoretical and practical aspects. My thesis builds upon the work of Sun (1999) by considering in greater depth his findings in SSD. It examines the association between Software System Development and its context, and the importance of the situated nature of software system development. The particular context of finance is considered. Key issues concerning the application of computer-based technology in finance motivate a re-thinking of SSD in the finance context through the adoption of EM principles and foundations. Four case studies pertaining to the three identified levels of finance are considered. These case studies support my thesis contribution by:

- establishing new foundations for software system development in the financial enterprise that guide software integration and building virtual environments for collaboration;

- proposing an open financial market model to support software system development meeting various needs of the new financial market model including learning, decision support, and modelling of the trading process;
- considering the importance of distributed modelling for software system development for financial engineering;
- considering the relationship between the software system development cycle and the finance research development cycle.

The thesis sheds light on the development of EM technology from a technical point of view and with reference to its future prospects. With its wider view of the computational activity, EM technology has offered both strategic and tactical support to my research, and empowered it with principles that helped in uncovering hidden relationships between the two domains computing and finance.