Requirements Engineering: Panacea or Predicament?

Professor Pericles Loucopoulos
OUTLINE

THE STATE OF PRACTICE & RESEARCH

CHALLENGES TO R.E.

RESEARCH ISSUES FOR R.E.
Requirements & R.E.

- Requirements
  - A set of desirable **functional** and **non-functional** properties that must be possessed or met by a system or system component to satisfy an agreed set of **organisational goals**

- Requirements Engineering
  - “The branch of systems engineering concerned with ‘real-world’ goals for, services provided by, and constraints on, software intensive systems” [1]
  - “The systematic process of developing requirements through an iterative co-operative process of analyzing the problem, documenting the resulting observations in a variety of representation formats an checking the accuracy of the understanding gained” [2]

Requirements Lifecycle

Requirements Engineering

Requirements Development
- Elicitation
- Analysis
- Specification
- Validation

Requirements Management
- Traceability: Tracking where requirements are met
- Change Mgmt: Req’mnt maintenance & propagation
- Fulfillment: Results & confirmation of successful fulfillment

Stakeholder consultation, review and context normalization
Understanding of desired system
Structured documentation of desired system
Identification of omitted, redundant & inconsistent req’mts
About Requirements Engineering

- It has a 40 years history
- Much research activity as evidenced by
  - 17 volumes of Requirements Engineering journal
  - Many conferences and workshops (IEEE/ACM RE, REFSQ, REPOS, Agile RE, REET, REV, MoDRE, WER, CAiSE, ICSE)
- Considered by industry as a most critical development activity
A Study 20 Years Ago

$4.5M - 17 Projects from
- Manufacturing
- Telecommunications
- Consumer electronics
- Aerospace

**Approach**

- Business Milieu
- Company
- Project
- Team
- Individual

**Findings**
- The thin spread of application domain knowledge
- Fluctuating and conflicting requirements
- Communication and coordination breakdowns

**References**
Consider a procurement project for a national health service for which different bids may be made.

Requirements need to be defined in sufficient abstraction so that a solution is not pre-defined and as to allow alternative technological implementations.

Once the contract has been awarded the contractor must write a definition as a reference document against which the contract can be validated by the client.
Separation of Concerns

- **User requirements**
  - Statements in natural language plus diagrams of the services the system provides and its operational constraints. Written for customers.

- **System requirements**
  - A structured document setting out detailed descriptions of the system’s functions, services and operational constraints. Defines what should be implemented so may be part of a contract between client and contractor.
Examples of Requirements

- **Functional requirements**
  - “If a patient requires multiple drugs treatment the system should warn physicians about conflicting medications”

- **Non-functional requirements**
  - “System downtime should not exceed 10 seconds”

- **Domain requirements**
  - “The system must be implemented in a way that patient information conforms to the statutory personal data protection act”
The State of R.E. Practice

- Survey of 808 participants

- Key findings
  - requirements used for both innovation and enhancing existing products
  - mixed approach to requirements
  - process is complex due to number of requirements as well as continuous change of requirements
  - ‘primitive’ tools still used

- Let’s have a look at some data

Source: Jama Software Survey (2011)
Understanding Customer Needs

Requirements are building blocks of innovation. What are your company’s biggest challenges? Mark all that apply.

- Gaining a clear understanding of what our customers want: 72.9%
- Documenting all the requirements: 58.9%
- Ensuring what’s built is what was planned: 50.7%
- Prioritizing requirements to decide what to build next: 46.9%
- Communicating requirements to the team: 43.7%
Dealing with Volume of Requirements

Let’s talk about complexity. On average, how many requirements does a project contain?

- 34.3% less than 500
- 25.4% less than 100
- 16.1% 1,000 to 5,000
- 20% 500 to 1,000
- 4.3% more than 5,000
Approaches Used

What software development process does your team use?

- Hybrid? 39.9%
- Waterfall or modified waterfall 25.9%
- Agile 19.2%
- Iterative or spiral 8.4%
- Other 4.3%
- RUP 3.7%
- We don’t believe in process 3%
The state of R.E. Research

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Volume of Research Output

Comparison of research categories

Requirements Engineering Journal and Requirements Engineering Conference Proceedings

- 1. Modelling: 60%
- 2. Viewpoints: 11%
- 3. Scenarios: 16%
- 4. Group dynamics: 8%
- 5. Issue deliberation: 5%
OUTLIN

THE STATE OF PRACTICE & RESEARCH

CHALLENGES TO R.E.

RESEARCH ISSUES FOR R.E.
Annual increase in cost €4.5 billion

Projects are expected to meet requirements but overall cost & time exceed approval

Project cost and time performance has deteriorated in year

Overall delay 18 months

Four Legacy projects account for the majority of in-year cost increase and time slippage

Ministry of Defence: Major Projects Report

Projects are over approval by €4.5 billion

Projects are 334 months over approval

Projects are expected to meet requirements

Most projects have experienced cost increase & time slippage

Performance against over half of the factors responsible for cost variation has worsened in last year

Performance against over half of the factors responsible for time variation has worsened in last year

A Study 4 Years Ago
# Recommendations

<table>
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<th>Lessons Learned</th>
<th>Recommendations</th>
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<td>The need to address the possibility of a fresh Assessment Phase when there has been a change of procurement strategy</td>
<td>Flexibility in design process</td>
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<td>The importance of identifying risks and appropriate mitigation strategies from the start of a project onwards</td>
<td>Strategy on risk evaluation</td>
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<td>The importance of getting early clarification of industry’s understanding of the requirement and ability to meet it</td>
<td>Relevance of requirements</td>
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<td>The need to build flexibility into the budget to respond to unforeseen events</td>
<td>Flexibility in plan</td>
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<td>The need to address the degree to which optimism may be driving key decisions</td>
<td>Evaluation of alternatives</td>
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*Source: Ministry of Defence*
Why is R.E. Hard?

- Businesses operate in a rapidly changing environment
- Different stakeholders have different goals, and priorities
- It is not clear at the outset of what exactly the value of the system might be
- Requirements are influenced by political considerations that are not normally externalized
Dimensions of Requirements

Challenges

- Despite the plethora of practical methods, techniques & tools practice still suffers.

- Research has not been successfully transferred to practice except perhaps for some standards e.g. OMG.

- Real world requirements for new systems raise new challenges.
Towards a New Business Ecology

- A shift from physical, to service to digital wealth
- Understanding people’s behaviour and using it for their benefit or using it to gain revenue

Ex1: Lifelong contextual footprint
- where we have been, with whom, at what pace etc
- a balance between economic benefits and issues about privacy, trust and security
- services of the future will focus on this balance

Ex 2: Energy
- understanding consumers’ behaviour
- adapting supply & demand
Information Processing

1 exabyte = 1 billion gigabytes

Implications

- 60%-70% refers to individuals
  - 50% of this attributed to individual’s actions
  - The rest is ‘ambient’ content

- 85% of this information runs through digital devices owned by enterprises
  - Enterprise **liability** – security, privacy
  - Enterprise **responsibility** – search, discovery, environmental footprint
  - Enterprise **opportunity** – innovation, transformation
Digital Economy

- “Data is the new class of economic asset like currency & gold”
- A study of 179 large companies found that those adopting “data-driven decision making” achieved productivity gains that were 5-6 percent higher than any other factor
Utility at Different Levels

**Individuals**
- **Data Type:** 'Crowdsourced
- **Incentives:** Pricing/offers, improved service
- **Requirements:** Privacy standards, 'opt out' ability

**Public Sector**
- **Data Type:** Census, health, tax
- **Incentives:** Improved services, efficiency in expenditure
- **Requirements:** Privacy standards, 'opt out' ability

**Private Sector**
- **Data Type:** Transactions, spending & use
- **Incentives:** Customer behaviour, prediction on trends
- **Requirements:** Business models

- Faster Outbreak Tracking & Response
- Improved Understanding of Crisis Behavior Change
- Accurate Mapping of Service Needs
- Ability to Predict Demand & Supply Changes

Source: Big Data Big Impact, World Economic Forum, Jan 2012
Example: AMR’s in Germany

- According to EU directive, 80% of households will have to have smart readers (AMRs)
  - For a large to medium sized German utility, which has about 240,000 conventional meters, quarter-hour meter readings would produce 960,000 sets of meter data to be processed and stored each hour once replaced by smart meters.

- The technology
  - Available technology to read data, deliver data, timestamp data.
  - Available technology to manage ‘big data’

- The use
  - Data can be relevant to different market players in different resolutions and aggregations as a basis for other services.
  - New features like complex tariffs, load limitations etc.
  - Optimization of processes with respect to quality, speed and costs
  - Leading to new services, products and solutions – some of which we do not even know today.
THE STATE OF PRACTICE & RESEARCH

CHALLENGES TO R.E.

RESEARCH ISSUES FOR R.E.
A Change in Focus for R.E.

<table>
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<th>TRADITIONAL</th>
<th>CONTEMPORARY</th>
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<tr>
<td>The context is a reasonably <strong>stable</strong> system ecology</td>
<td>The context is a <strong>rapidly changing</strong> system ecology</td>
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<td>Emphasis on business process improvement via IS</td>
<td>Emphasis on enterprise and market transformation via IS</td>
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<td>A key issue is that of <strong>alignment</strong></td>
<td>A key issue is that of <strong>innovation</strong></td>
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<td>System properties <strong>predictable</strong></td>
<td><strong>Emergent</strong> system properties</td>
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<td>Development based on a <strong>decision</strong> paradigm</td>
<td>Development based on a <strong>design</strong> paradigm</td>
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<tr>
<td>Clear <strong>separation</strong> between system and user</td>
<td>The human is no longer outside the system but an <strong>integral</strong> part of it</td>
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*(see Dustdar’ keynote talk)*
NSF-funded Project

- Workshop held in Cleveland
  - see http://weatherhead.case.edu/requirements/reqs-attend.html

- workshop held in Dagstuhl
  - see http://www.dagstuhl.de/en/program/calendar/semhp/?semnr=08412

Aims and scope of the Initiative

- Objective was to “bring new paradigms, concepts, approaches, models, and theories into the development of a strong intellectual foundation for software design” (Call for SoD) as it relates to the process of capturing and managing design requirements.

- Develop principles, theoretical foundations and practical guidance for identifying, soliciting, deriving and managing design requirements for software intensive systems in the 21st century.
Motivation for Workshops

- Software design involves much more than its traditional focus

- Different contexts
  - Organization design (organizational design options, rules/routines, business models, and change)
  - Industrial design (e.g. pervasive applications),
  - Media design (e-commerce and media applications),
  - Human computer interaction design (new modalities of interaction),
  - Business architecture and modular design (e.g. open business platforms),
  - Design theory (cognitive models, design principles)
Research Issues

■ On the R.E. Process
  ■ What are the fundamental concepts of design and their influence on requirements?

■ On Intertwining
  ■ What are mutual impacts between system and environment?

■ On Evolution
  ■ How to deal with multiple stakeholders’ requirements over time?

■ On Conceptual Modelling
  ■ How to deal with a plethora of modelling paradigms?
Research Challenge: R.E. Process

“A point I want to emphasize in the requirements process is we do not usually know what the goal is. I will assert that this is a deep fact of reality that is ignored in much of the literature about requirements. We do not know what we are trying to build. The hardest part of most designers of complex systems is not knowing how to design it, but what it is you are trying to design. When we talk about eliciting requirements, we are talking about deciding what it is we are trying to design”

Fred Brooks

- We do not know the development goals at the outset
- The development tree emerges as we progress
- The development tree is not about decisions but about tentative designs
- The goodness function cannot be evaluated incrementally, the whole tree has to be searched
- The constraints keep changing

Fred Brooks (2010), The Design of Design, Addison-Wesley
Related Work

- A number of empirical studies e.g. [1] have shown that
  - There is no meaningful division between analysis and synthesis but rather a simultaneous learning about the nature of the problem and the range of possible solutions
  - A design solution may itself lead to a new design problem
- “As one ponders the tradeoffs there comes a new understanding of the problem in hand and with it may come a change in design goals” [2]
- The use of models is significant in the design process [3]
  - Models are not just outputs but are also inputs to the thought process

Interrelated Concerns

- Group modelling
- Stakeholder workshops
- Simulation running

- Domain ontology
- Stakeholder goals
- Process models
- Scenarios

- Systems thinking
- Abstract thinking
- Operational thinking
- Solution-first thinking

- Group modelling
- Stakeholder workshops
- Simulation running
Orthogonality of Modelling Views

Strategy-oriented Modelling

Service-oriented Modelling

Support-oriented Modelling

WHY

WHAT

HOW
Can we deploy alternative methodological strategies to suit the emergent problems?
Reasoning about the process

Research Challenge: Intertwining

- The interplay between ‘subject’ and ‘system’ worlds has become more intricate, complex, dynamic and emergent

- Should design requirements be considered as part of a multi-system, socio-technical ecology that drives organizational innovation?
The AMR Example

- Financial factors
  - Investment on AMR technology
  - Revenue
  - Wom gaining
  - Customer satisfaction

- CRM factors
  - Wom gaining
  - Customer satisfaction

- Environmental factors
  - Energy consumption information
  - Energy efficiency measures

- HR factors
  - MR Staff needed
  - Fuel usage
  - CO₂ emissions

- AMR installation Rate

- Financial factors

- CRM factors

- Environmental factors

- HR factors
Business Goals & Requirements

1. To reorganize the PPC distribution to comply with the EU rules.

1.1 To enter the competition market

1.1.1 To provide effective commercial services for non-eligible customers

1.1.2 To provide effective commercial services for eligible customers

1.2 To introduce means for Third Party Access
Business Goals & Processes

Teleology of Services & Systems

Enterprise Goal: Satisfy customer electrification requests

Enterprise Process: Electricity supply application fulfilment

Actor 1

Actor 2

Actor n
Research Challenge: Evolution

- The fluidity of design artifact drives the change process
- How to deal with run-time requirements change i.e. once system has been deployed?
- Evolution at an abstract level
  - Ontology of requirements according to their source?
  - To evolve an information system it is necessary to evolve its conceptual schema. How can we make the evolution of a conceptual schema more effective and more efficient?
  - How is requirements evolution related to contextual factors, and goals?
The Trajectory of Artifacts

Ontology for Change

- Develop techniques and tools for dealing with different classes of requirements

- Hard requirements
  - goals
  - global constraints

- Preferences
  - goals
  - constraints
  - business rules
  - soft goals/ criteria

- Priorities on preferences

- Hard requirements are stable, preferences change often, priorities change very often

Credits to John Mylopoulos for discussion at Cleveland workshop
Test-Driven Conceptual Modelling?

The current state

- Ensure product quality
- Satisfy customer requests
- Supply LV customers with electricity
- Alter characteristics of existing customer installation
- Ensure safe and continuous electricity provision
- Handle financial aspects of electricity supply to customers
- Change ESIC distribution to comply to the E.U. rules
- Enter the competition market
- Introduce means for TPA

Contextual forces

- Distribution requirements
- Change process model

Reasoning about Change

Modelling scenaria for change

Change process model
Research Challenge: Modeling

- Modeling is central to R.E.
- There is a ‘Tower of Babel’ of paradigms that hinders the application of models in practice (see Karagiannis’ keynote talk)
- Can we effect some form of unification?
- How can we use models as an exploration of the problem rather than as a solution to the problem?
- How can we use models as archetypes?
Orthogonality of Modelling Views

- Strategy-oriented Process Modelling
- Service-oriented Process Modelling
- Support-oriented Process Modelling

WHY

HOW

WHAT
A Unified BP Meta-model
Independent to Notation we can check for

- Performance
  - Throughput
  - Execution time
  - Timeliness
  - Execution Cost

- Efficiency
  - Time
  - Resource
  - Cost

- Reliability
  - Reliability
  - Recoverability

- Availability
  - MTTF
  - MTTR

- Security

Quality-centric Modeling

Models for exploration

- Validity of a model is impossible to prove
  - Validation or proof-theoretic approaches are based on certain assumptions
  - Assumptions themselves may be invalid

- We must turn attention to gaining confidence in the model
  - Model to be discussable by stakeholders
  - Model to be testable for behaviour using different stakeholders’ parameter instantiation
**Stakeholders in Model Exploration**

- **Stakeholders express goals**
  - Introduce efficient personnel exploitation
  - Perform benchmarking of personnel requirements
  - Introduce personnel training to become multiskilled
  - Introduce personnel reallocation
  - Introduce hiring of personnel with new skills
  - Introduce personnel incentive schemes
  - Improve methods of personnel evaluation
  - Improve work safety
  - Define positions according to flexible organisation
  - Compare positions according to ESI norms
  - Introduce personnel reallocation within Distribution BU
  - Introduce personnel reallocation outside Distribution BU

- **Problem area processes are defined**
  - Spectators in Holding Area
  - specs receiving queue mgmt
  - Spectators in Security Check Queue

- **Stakeholders set ‘what-if’ scenarios**
  - Simulated behaviour feeds decisions
Archetypal Models

The Doric column

The Parthenon

repeated 92 times in the Parthenon

The Poseidon Temple at Sounion

and 38 times in the Poseidon Temple

A Metaphor
Example of Archetype

Programming

- Programmers
- Lines of Code
- generating code
- code generating productivity

Oil Prospecting

- Oil in Ground
- Oil Wells
- pumping
- Oil in Storage Tanks
- pumping productivity

Debt Accumulating

- Cash
- Debt
- paying Interest
- interest rate
Conclusions

- Requirements is arguably a most critical activity in the system development lifecycle

- **PANACEA**
  - Many regard existing R.E. approaches as sufficiently robust and relevant

- **PREDICAMENT**
  - New business models and technologies have highlighted the inadequacy of contemporary RE techniques

- We outlined the need for a new research landscape in RE building on existing successes

- The proposed research themes represent a realistic research agenda which is likely to yield substantial benefits to the community
THANK YOU