Introduction to Software Requirements Engineering

Part 1: Domain Knowledge

Björn Regnell

Updated: 2024-03-19

License: CC-BY-SA
https://github.com/bjornregnell/reqeng-book

Part 1: Domain Knowledge

Outline

What is Requirements Engineering (RE)?

- RE is focused on the
  - **features** of software systems
  - **system context**, including users and connected systems
  - **development context**, including stakeholders' intentions
- The RE process involves
  - knowledge-building
  - consensus-building
  - decision-making
  - innovation
  - communication

research
agree
choose
generate ideas
be pedagogical

What is a requirement?

- A simple definition:
  - Something **needed** or **wanted**.
  - A documented **representation** of something needed or wanted.

- Are we representing what is **actually** needed or wanted?
- *'Requirement'* can in practice mean many different things: must, option, idea, innovation, intent, rationale, function, quality, design, feature, decision, constraint, ...
- The most **general** meaning:
  any kind of **information entity** used in RE

Core Activities of RE

- The 4 core activities of RE are:
  - **Elicitation** learning
  - **Specification** representing
  - **Validation** checking
  - **Selection** deciding
- In practice, these activities are often
  - **Interdependent** output of one is input to others
  - **Concurrent** one activity triggers others
  - **Continuous** throughout the product's life as it evolves

What is good RE?

- Feasible and helpful foundation for software development
- Cost-effective process with high artifact quality
- Happy stakeholders
- Good system
  - commercially successful
  - beneficial to its users
  - ethical, helpful to society
- When are we ready? What is good enough?

RE in the Development Process

- RE interprets stakeholders intentions into validated req specs
- RE provides input to, and learns from down-stream activities
  - System Design
    - Quality reqs determine architectural decisions
  - System Implementation
    - Functional reqs (data and logic) are realized in code
  - System Verification
    - The req spec define correct output in test cases
  - System Operation
    - User feedback is input to requirements evolution
- As requirements evolve you must manage impact of changes
- Traceability:
  - Links among artifacts to support change management
  - Forwards: from requirements to down-stream activities
  - Backwards: from requirements to stakeholders

Requirements as Solution Constraints

- U: the **universe** of all possible software systems
- S: the **solution space**, a subset of U including all systems that **fulfill the spec**
- S contains both "**good**" and "**bad**" systems
- The **general purpose** of RE:
  - to **constrain the solution space** so that software development is likely to produce a **good enough** solution
- The req spec should be a good enough definition of what we mean with a "good enough solution"
- RE is the **foundation for software quality**.

Requirements Selection Quality

Requirements Selection means deciding which features to release.

- What is a good selection decision?
- **If** we had perfect information about all requirements **and** the ability to precisely predict the future **then** we could partition all requirements based on their quality (value versus cost):
  - **Alfa**-requirements: should be *selected* with perfect wisdom
  - **Beta**-requirements: should be *rejected* with perfect wisdom

		Decision	
		Selected	*Rejected*
Requirements Quality	*alfa*	*A* Correct selection ratio	*B* Incorrect selection ratio
	beta	*C* Incorrect selection ratio	*D* Correct selection ratio

Product quality: $\frac{A}{A+C}$ Selection quality: $\frac{A+D}{A+B+C+D}$

Common Acronyms

RE	requirements engineering
SE	software engineering
SW	software
HW	hardware
FR	functional requirements
QR	quality requirements
SRS	software (or system) requirements specification
req	requirement
spec	specification
constr	constraint
sys	system
dev	development
ops	operations
org	organisation

What is a Requirements Specification?

- A simplistic definition:
  - *"A document that describes what the system should do"*
    - what is what and what is how?
    - how much about the context is needed?
    - not always a document; database, issue tracker, prototype, ...
- A collection of requirements models + Help for the reader
- Expressed using a combination of suitable media, such as:
  - text
  - diagrams
  - prototypes
  - test cases
  - videos
  - ...
- Similar to a shopping list:
  - You don't always get what you want.
  - You often want things that you don't need.

Different kinds of requirements

- (Parts of) Requirements are often labeled as:
  - **Functional Requirements** (FR), including:
    - Requirements on **Data**
    - Requirements on **Logic**
  - **Quality Requirements** (QR)
    - Accuracy, Capacity, Performance, Reliability, Usability, Safety, Security, ...
- In practice FR and QR are often **combined** and **related**:
  - Functions have quality:
    - a function can be unreliable and unsafe due to bugs
  - Logic and data is related:
    - functions have input, state, output
  - Quality is supported by functions:
    - a login function supports system security

Requirements at different levels

- Level of **design abstraction**: from 'why' to 'how'
- Level of **detail**: amount and richness of information
- Level of **aggregation**: grouping, hierarchical decomposition
- Level of **formality**: from unstructured to mathematical

Abstraction on the Goal-Design-scale

why $\rightarrow$ *what* $\rightarrow$ *how*:

- **Goal-level**: why?
  - focus on intentions of stakeholders and users
- **Domain-level**: what do users do with the system?
  - focus on usage context of a feature, normal and exceptional usage, domain events
- **Product-level**: what does the system do?
  - focus on system behavior, input-logic-state-output, normal and exceptional input/output, product events
- **Design-level**: how?
  - up-front design choices, implementation details
  - really required/justified? often better as example only, not req

Which level is best? It depends. They are often combined.

- Too much 'how' may over-constrain the solution space giving too little freedom for developers to find the best solution.
- Without 'why' the risk of an unsuccessful solution is high.

Levels of Formality

From unstructured to mathematical:

- Very informal: free-form representation, no explicit rules
- Very formal: syntax, semantics, inference, meta-language
- Pragmatic middle-ground: restricted natural language + diagrams with explanations
- Pro: Formality enables automatic checks, concise models, ...
- Con: Formalization requires effort, knowledge, skills, ...

Level of formality? – a difficult tradeoff

- Formality in various aspects to a varying degree:
  - Very informal: free-form representation, no explicit rules
    - examples: slide presentation, textual narrative
  - Very formal: formal syntax, operational semantics, inference
    - examples: state machine, regular expression, predicate calculus
- Advantages of formalization:
  - Reduced ambiguity
  - More concise models
  - Enables tooling: automatic checks, proof of soundness, ...
- Disadvantages of formalization:
  - Harder to understand
  - Requires effort, specialized knowledge and skills
  - Limited in scope and expressive power
  - Some stakeholders cannot contribute in validation

Automated support for RE

- Why tools?
  - We want to boost our productivity.
  - The amount of information grows very quickly.
  - We need to adapt different views to specific stakeholders.
  - We need support for searching and summarizing.
  - Manual traceability management is very tedious!
  - Natural language Processing (NLP)
  - Large Language Models (LLM)
- Which tools?
  - Generic tools for writing, drawing, databases, ...
  - Specialized tools, e.g. DOORS, Jira, openproject.org, ...
  - Artificial Intelligence for RE
  - AI support to elicit, specify, validate, select
- Meta-level RE: RE for Tools for RE
- Educational prototype `reqT`: Lab tool for learning RE
  - `https://github.com/reqT/`
  - Structured Natural Language, tree-like data structure

Explicit or implicit requirements?

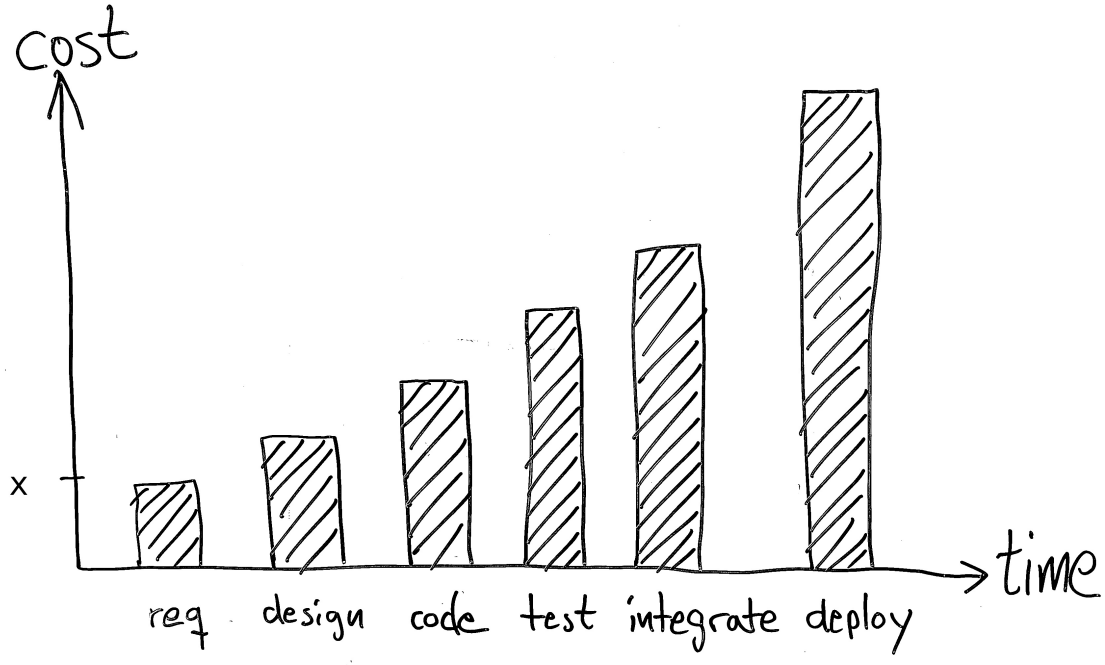
- **Explicit** requirement:
  - has a unique id, such as a mnemonic (short name) or number
  - often has status, priority, or similar
  - often has an explicit "shall"-statement
  - often has links to other related spec parts with id
- **Implicit** requirement:
  - part of spec but no id, no status, no "shall"
  - is text/diagram a requirement or just help for the reader?
- Advice:
  - Make most important requirements explicit.
  - Link diagrams to explanatory text with explicit requirements.

What is a good enough requirements specification?

Example of **quality factors**:
can only be achievable to some degree; can be conflicting

- **Correctness**: represents the stakeholders' intentions
- **Unambiguity**: stakholders have similar interpretation
- **Completeness**: most of important relevant aspects included
- **Consistency**: no contradictions among requirements
- **Conciseness**: suitable level of abstraction and detail
- **Comprehensibility**: understood by stakeholders
- **Verifiability**: possible to check fulfillment
- **Feasibility**: possible to implement, value to justifiable cost
- **Traceability**: reqs can be referred to, can find origin of reqs
- **Modifiability**: easy to change, good structure
- **Ranked**: includes assessment of importance and stability

Cost of RE defects



- The cost of req defects increase with time.
- A req defect that costs x to fix in req validation may cost $100x$ or even $1000x$ in production.
- Why may cost of req defects increase exponentially?
  - Number of dependent artifacts multiply over time
  - If the foundation changes, many things need to be updated

How to best do RE is highly context-dependent

Aspects of the RE context to consider:

- **Stakeholder configuration**: relation customers – supplier
  - Examples of customers (users) and suppliers (developers): *public authority, private consumer, individual contributor, company (system integrator, subcontractor), community, company, company-internal department, ...*
- **Business model**: risk-sharing, profit-sharing:
  - internal budget, license fee, subscription, freemium, ad-based, donations, open-source community, non-profit, ...
- **Delivery model**: one-off, eventually updated, continuous integration and delivery
- Questions regarding customer–supplier relation:
  - Who has the knowledge
  - Who has the power
  - Who gets the biggest value/profit? short- vs long-term
  - Who takes the biggest risk?

Type of product

- Level of customization
  - generic
  - customer specific
- Hardware integration:
  - HW+SW
  - Pure SW
- Network integration
  - off-grid
  - connected
  - distributed
  - concurrent massive multi-user online communication, ...

Examples of common RE Contexts:

- Public tender: a public authority invites suppliers to bid
- B2B: both customer and supplier are companies
- B2C: the supplier provides SW to a consumer market
- In-house: one org develops system for internal use
- Open-source library: organisations share SW investments
- Embedded system
- Webb app: backend-frontend
- High-assurance systems: security and safety is critical

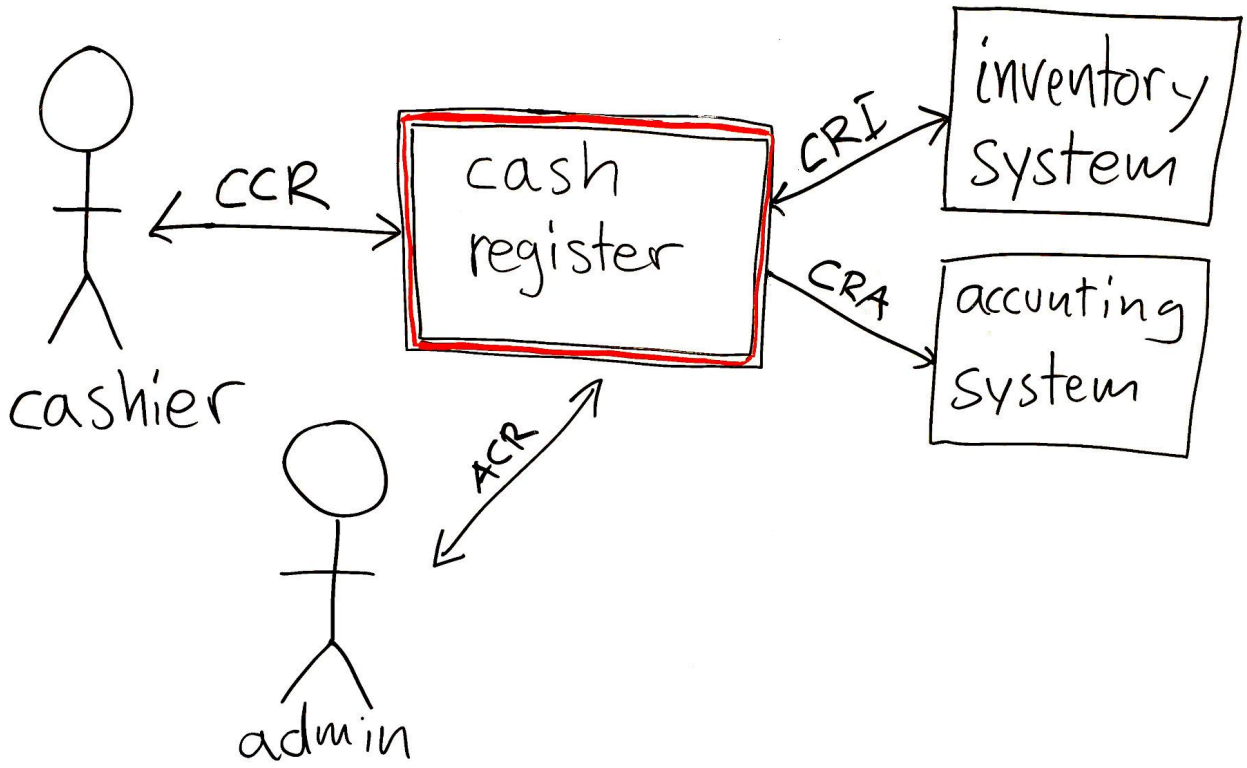
Scale of RE

- The RE effort increases exponentially with size!
  - Number of requirements: N
  - Number of pairwise relations: $R = N(N-1)/2 \approx N^2$
- Orders of magnitude:
  - **Small-scale RE**: $N \approx 10^1$, $R \approx 10^2 = 100$
    - requires small effort, all pairwise relations can be considered
  - **Medium-scale RE**: $N \approx 10^2$, $R \approx 10^4 = 10\ 000$
    - feasible but requires large effort, consider subset of relations
  - **Large-scale RE**: $N \approx 10^3$, $R \approx 10^6 = 1\ 000\ 000$
    - unfeasible unless requirements are bundled into groups with high cohesion within groups and low coupling across groups
  - **Very large-scale RE**: $N \approx 10^4$, $R \approx 10^8 = 100\ 000\ 000$
    - unfeasible even if requirements are bundled into groups as the groups become either too many or too large
    - feasible only if the system can be split into subsystems with independent RE

Context Diagram

- A diagram describing the environment of the product
- The named product in the center as a **closed** box
  - no internal structure is shown – the focus is on context
  - open box with system parts inside is an *architecture* diagram
- Entities interacting with the product are connected by arrowed lines to show data flow direction
  - User roles (actors), shown as straw man icons
  - Other connected systems, shown as named closed boxes
- **Inner domain**: *direct* interaction with product
- **Outer domain**: *indirect* interaction with product
  - often *not* included in the context diagram
- Accompanying explaining text, including explicit requirements: "the system shall have interface X"

Context Diagram Example



* Interface CRA:
  * Spec: The system shall ... data entities ...

What is requirements elicitation?

- Engaging with stakeholders
- Building domain knowledge
- Discovering and inventing requirements
- Exploring contextual usage
- Starting-points:
  - Stakeholder Analysis
  - Context Diagram
  - Product Scoping

Why is elicitation so hard?

Elicitation challenges: Stakeholders often...

- cannot abstract
  - difficult to explain what they do and why
  - difficult to express what they (really) need
  - ask for specific solutions
- lack imagination
  - of new ways of working
  - of consequences of new solutions
- complicate the picture
  - have conflicting demands
  - actively resist change
  - have luxury demands, "gold plating"
  - have new demands once others are met

Elicitation Methods

- Overview of elicitation methods:
  - Surveys
  - Interviews
  - Case-studies, examples: demos, usability tests
  - Creativity methods, example: brainstorming, focus groups
  - Operation Data Analysis: example: telemetry
  - Business Intelligence: observing competitors
- Elicitation methods support specification, validation and selection, example: focus groups support selection, usability testing support validation

Surveys

- Good for asking many persons to get an overview of distribution of views
- TODO!!! topics to consider
  - Population definition and sampling
  - Response rate
  - Closed and open questions
  - Lickert Scale
  - statistics, correlation, etc.

Interviews

- Unstructured interviews: open questions, open topics
- Structured interviews: closed questions, focused topics
- Semi-structured: combine both

Case Studies with Stakeholders

- Demonstrations by stakeholders
  - task enactment in a specific usage context
- Observation of stakeholders
  - sometimes it is easier to show than tell
- Prototyping (has its own chapter)
- Usability testing (has its own chapter)
- Pilot product deployment
  - limited but real usage of system in production
  - sometimes deployment is higher risk than development

Operation Data Analysis

Observe system in production before subsequent evolution

- Usage statistics, telemetry
- Online user experiments, A/B-testing
- Feedback from marketing
- Feedback from support
- Engage with user communities
- Mining social media

Creativity Methods

Group activities that support innovation.

- Purposes:
  - trigger change and give competitive advantage
  - facilitate stakeholders in idea generation and assessment
  - get feedback on novelty and market opportunities
- Example methods:
  - Brainstorming: free-form idea generation without assessment
  - Focus-groups: structured brainstorming with assessment
  - Creativity Workshops: explore, combine, transform

Creativity Workshops

Workshops based on applied creativity theory including:

- Exploratory phase: opening up the space of ideas
- Combinatorial phase: combining ideas to generate new ones
- Transformational phase:
  - change problem space so something that is impossible now becomes possible
- Analogical reasoning:
  - transfer knowledge from analogical domain
- Storyboarding:
  - integrate ideas related to selected use cases

Requirements Selection

- Requirements Selection provide input to downstream activities, answering the question:
  - What features are currently in and out of scope?
- Requirements selection includes:
  - **Prioritization**
    - ranking of requirements based on aspects such as benefit, cost, risk
  - **Product Scoping** (own chapter)
    - Defining the scope and theme of each release
    - Release Planning: deciding the feature set included in each release, while taking into account resource constraints and priorities

Why Prioritize?

- To focus on the most important issues
- To find high and low priority requirements
- To implement requirements in a good order
- To save time and money

Prioritization steps

- Select prioritization aspects (e.g. benefit, cost, risk)
- Select prioritization objects (e.g., features)
  - Try to define features at a high-enough level that can be selected or de-selected independently (if possible)
- Structure and groups objects
- Do the actual prioritization
  - Decide priorities for each aspect, for each object
- Visualize, discuss, iterate...

Why is prioritization hard?

Prioritization challenges:

- Finding a good abstraction level
- Combinatorial explosion
- Inter-dependencies
- Not easy to predict the future
- Power and politics

Prioritization Aspects

Examples of prioritzation aspects:

- Importance (e.g. financial benefit, urgency, strategic value, market share...)
- Penalty (e.g. bad-will if requirement not included)
- Cost (e.g., staff effort)
- Time (e.g., lead time)
- Risk (e.g., technical risk, business risk)
- Volatility (e.g. scope instability, probability of change)
- Other things to consider:
  - competitors, brand fitness, competence, release theme
- Combine and optimize aspects, e.g.:
  - cost vs. benefit, cost vs. risk, importance vs. volatility
  - maximizing benefit while minimizing cost

When to prioritize?

- Before spending large RE effort on a specific feature
- At decision points, e.g.,
  - Start of feature design
  - Start of feature implementation
  - Release Planning
- When big changes occur
- Regularly with *lagom* intervals

Who should prioritize?

Find the right competence for the right aspect

- **Developers** know about e.g.,
  - development effort and engineering risk
- **Support** organization knows about e.g.,
  - customer value if included and cost penalty if excluded
- **Marketing** organization knows e.g.,
  - competitors' products, market opportunities, cost of sales
- etc...

Prioritization Scales

- For each aspect you need to decide on a metric
- A metric is expressed/estimated using a value on a **scale**
- Different types of scales with different power:
  - categorical scale $\{A, B, C\}$
    - example: {must, ambiguous, volatile}
  - ordinal scale $A > B$
    - examples: higher value, more expensive
  - ratio scale $A = k \cdot B$
    - examples: amount of money, hours, percentage

Prioritization Methods

Different methods, can be combined

- Grouping, categorical scale
  - example: use post-it notes on a white-board to group interdependent features
- Top-N, e.g. $N = 5$, categorical combined with ordinal
  - example: select 5 most beneficial features from the viewpoint of a specific stakeholder
- Grading on an ordinal scale
  - examples: grading 1...5, high–medium–low
- Ordering by pair-wise comparison (sorting, ordinal scale)
  - use insertion sort to arrange in order of highest to lowest risk
- 100-dollar-test, ratio-scale
  - distribute fictitious money to reflect prioritization aspect

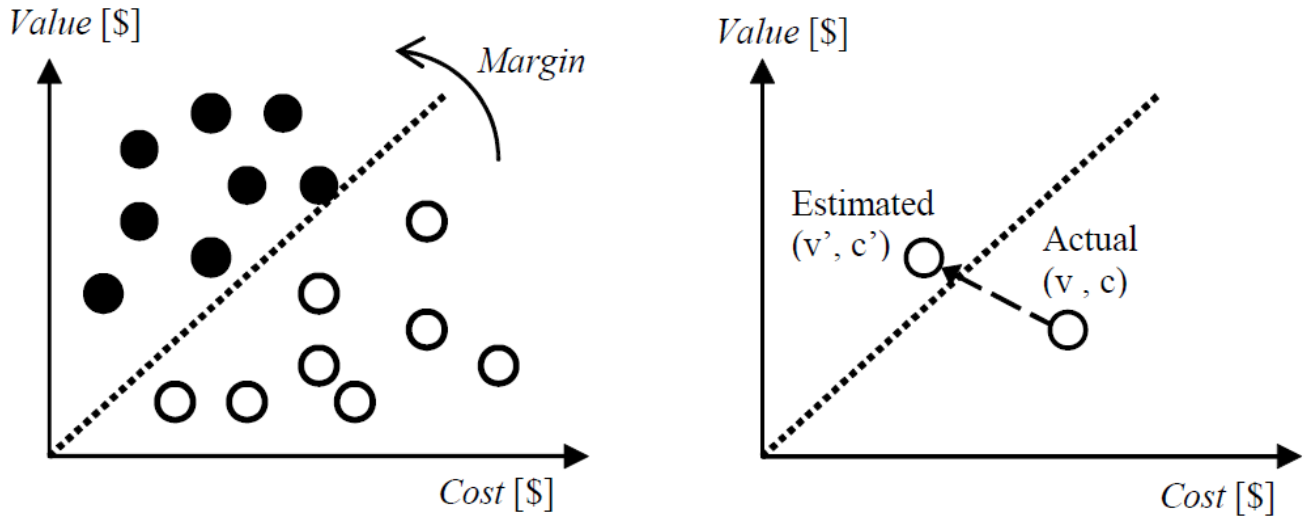
Prioritization Methods Combined

Example of how prioritization techniques can be combined:

- Start with a high-level grouping of features that are highly interdependent to reduce the number of prioritization objects
- Sort all features of small groups in benefit order
- Use Top-5 for groups with large number of features
- For selected groups that are most important for the coming release: do a ratio-scale prioritization with the 100-dollar-test

Cost-Benefit Diagram

Cost-value diagram with Alfa- and Beta-requirements.



Uncertain estimates of benefit and cost $\rightarrow$ sub-optimal decisions.

Prioritization as Constraint Solving

- TODO!!! Part of lab
- TODO!!! discuss circular inconsistency in pair-wise comparison