Requirements

Software Engineering
Computer Science 520/620
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Today’s Problem
Using some kind of approach like one of the following
Process model

• Earliest design and test

1970’s

• Recognition of feedback loops
  – Confined to successive stages
• “Build it twice”
  Early prototyping
Reuse Based Development

New Process
Requires data store semantics

Repository

"Throwaway" prototyping
Evolutionary prototyping

The Rational Unified Process

New semantics to show roles of agents
Boehm's Spiral Model

Different Traversals of the Spiral Model to address different risks

- Application reqmts = low risk
  - Budget, schedule = high risk

- Stable appl. reqmts & budget errors = high risk

- Application reqmts = high risk
  - Budget, schedule = low risk
To the satisfaction of all of these?

Our Approach

- What is the goal/role of each component type?
- What is the nature of it?
  - Eg. what internal structure does it have?
- What sorts of stakeholders are interested in it?
- What sorts of questions do they generally have about it?
- What sorts of relations must it participate in?
  - Internal relations
  - External relations
- What sorts of processes deal with it?
Requirements Spec.

Characteristics of System to be built must match required characteristics

Hi level design must show HOW requirements can be met

Test Results must match required behavior

Test plan exercises this code

Design

Hi Level consistent views

Low level

Code must implement design

Hi level design must show HOW requirements can be met

Consistent views

Low level

Code

Test plan exercises this code

Test Plan

This is the anchor
Some Papers in Requirements Engineering


Requirements: Goals and Purposes

Why “do requirements”?

- Clarify needs before plunging into design
  – Customer “knows” what is wanted
  – But usually doesn't know how to say it
  – Weak sense of what can be achieved
- Clarify acceptance criteria
  – How to know it really delivers what was wanted
- Serve as guide to developers, testers, customers, maintainers
  – “Baselining” requirements
Requirements Spec.  

Characteristics of System to be built must match required characteristics

Test Results must match required behavior

Design

Test Plan

Requirements Spec.

Functional  Safety

Robustness  Performance

Accuracy

Design

Modules  Components

Constraints  Design Decisions
Characteristics of system to be built must match required characteristics.
Requirements Specification Driven By Stakeholders and their Questions

- Customers
  - What must it do?
- Developers (eg. designers)
  - What do I have to get it to do?
- Testers
  - What is it supposed to be doing?
  - How would I know it if I saw it?
- Users
  - What is it supposed to do?
- Regulators
  - Is enough being required?
- Others???
Requirements Specification Parts

Help stakeholders organize their thoughts about needs by decomposing requirements specification into categories needs and desires.

Some examples:
- Introduction/Background
- Functional
- Environmental
- Performance
- Accuracy
- Robustness
- Security
- Safety

Background/Introduction

Purpose: Give background/context out of which the problem arises, and directions in which it is likely to go

Should contain glossary, references

Should give intuition about problem, domain, existing solutions, components

Probably best written mostly in natural language

Example: UMass has 20,000 students, slow growth next few years
Semester system
Existing system that works, but is not great
Define: FTE, fulltime load, etc.
Functional

Purpose: Indicate the functional transformations that the system will have to compute

Likely to be large and complex, therefore aids to easier and clearer comprehension are needed (eg. hierarchy)

Important to state WHAT the functions are and not HOW they are to be computed

Promising formalisms: dataflow diagrams, FSM’s

Usually the chief focus of a requirements specification, and of requirements formalisms--but non-functional requirements are often at least as important

Environmental

Purpose: Indicate the environment in which the software will have to operate

- On which hardware and software will the software run?
- With which other applications will it have to interface?
- What will be the nature of the user community it will have to support?
- With what other manual and automated systems will it have to interface correctly?

Example: System is to be interactive
Most users to be students
Must run using cellphones, PDAs
Must print reports on existing forms
Must interface successfully with existing student and administrative databases
Performance

Purpose: Specify how much computer and human resource can be allocated to support the execution of the software

How much computer memory can the software use?

How fast must response time be?
   --average case
   --worst case

How long will users wait for batch runs to terminate?

Example: 2 second response time
   overnight printing of all reports
   1 Gbytes of memory available
   500 GBytes of disk available

Accuracy

Purpose: Specify how much tolerance (if any) is acceptable in the results

Most important in numerical computations, but...

Often where "optimality" is defined
   eg: what is a "good" game of chess?

Example: Reject scheduling constraints that cause more than 10% of all student requests to be denied
Robustness

Purpose: Specify what sorts of abuse the software will have to resist, and how it will respond

What kinds of "illegal" inputs might be expected, and what should be done about them?

Must the system fail safe, fail soft? When?

What abnormal environmental conditions might be expected?

Example: System must never corrupt any database
--even after a crash
System must deny illegal requests politely
System must not crash due to
--lack of storage
--user overload

Security

Purpose: Specify which users can do which things, and when

Usually there are classes of users--what are they?

How to distinguish among the users?

Matrix (?) to specify what accesses and permissions different classes and users will have?

Example: Students cannot:
--change course assignments
--cancel courses
--access data on others
Faculty cannot:
--cancel courses
--change course assignments
Faculty can: access any student data
Administrators can: .... do pretty much anything...
Safety

Purpose: Specify what hazards must be avoided

Specify what the software must NEVER be allowed to do

Has some elements of an inverse or negated set of requirements

Example: System must never corrupt student information database, or faculty personnel database

Not All Go Into All Requirements Specs.

• Some of these may be omitted; some emphasized/deemphasized

• Other sorts of requirements may be added/substituted eg: reliability, flexibility, portability......

• Requirements specification provides information needed to satisfy needs of all stakeholders

• Different stakeholder mixes determine choices of what goes into the requirements spec.

SOME EXAMPLES OF THESE UNDERLYING NEEDS:

• Communication
• Testability
• Precision
• Clarity
• Completeness
• Changeability
Requirement Specification Challenges

- Is it **Complete**? (to the extent required)
  - Ultimately impossible to be sure about this
- Is it **Consistent**? (no internal contradictions)
  - Many possible interpretations of this
- Is it un**ambiguous**? (possible multiple interpretations)
- Is it sufficiently **precise**?
  - It is possible to be too precise too
- Is it **Feasible**?
  - If it asks the impossible it would be good to know it
- Is it **Even**? (consistent levels of detail)
- Is it **Understandable**? (what does that mean?)
  - by all stakeholder groups!
- Is there an implementation bias?
- Is there a good basis for proceeding to design?

A Requirement Specification Is Never Perfect in All (Any?) Aspects

- Imperfections are often understandable, tolerable, unavoidable
- Look at real underlying stakeholder needs for the requirements specification (communication, clarity, precision, modifiability....??)
- Plan requirements content, structure, relations to meet these needs
- Requirements specification medium is crucial in helping assure needs are met
- Select requirements specification medium to address needs
Requirements Specification
Formalisms and Processes

- Support addressing these challenges
- Different formalisms emphasize facilities for supporting the answering of different types of questions
- Different processes provide to different degrees of assurance and thoroughness

Requirement Processes

- Elicitation
  - How to ascertain requirements
  - Interviewing, classifying, organizing
  - Emphasis on perspectives/viewpoints
- Review
  - How to determine consistency, completeness, etc.
  - Emphasis on analysis
  - Need for semantic basis and inference reasoning
- Revision/improvement/enhancement
  - How to add, delete, modify
  - Rereview: how to determine consistency of modified requirement specification
Being Precise about Requirements Processes

- Helps developers understand
  - Other stakeholders too
- Basis for automated support
- Being precise about processes is closely tied to being precise about artifacts

Example Requirement Specification Process
Define Rqmt Element

- Define Functional
- Define Timing
- Define Accuracy
- Define Input/Output
- Define Robustness

Better Definition of Define Rqmt Element

- Define Functional
- Define Input/Output

Make Functional
- Fcn OK

Make Input/Output
- I/O OK
Better Definition of Define Reqmt Element

Define Rqmt Element

Define Functional

Define Input/Output

Make Functional

Make Input/Output

How to do this???

Helps if it is defined as a DFG
Many Details Left Out
Many Other Alternatives

- When to check what
- How to do the checks
- How to respond
  - And when
- Etc.
- Being more specific about process entails being more specific about artifacts/products

Focus on artifact specification approaches and issues

Evaluation of Requirements
Specification Media

Representative Evaluation
Criteria:

- UNAMBIGUOUSNESS
- CLARITY
- COMPLETENESS
- VERIFIABILITY
- CONSISTENCY
- MODIFIABILITY
- LIFECYCLE UTILITY
# Evaluation of Requirements Specification Media

**Representative Evaluation Criteria:**
- UNAMBIGUOUSNESS
- CLARITY
- COMPLETENESS
- VERIFIABILITY
- CONSISTENCY
- MODIFIABILITY
- LIFECYCLE UTILITY

**Example Specification Media:**
- NATURAL LANGUAGE
- STRUCTURED NATURAL LANGUAGE
- DIAGRAMS/CHARTS
  - DFD’s, FSA’s, Petri Nets
- FORMAL APPROACHES
- COMBINATIONS OF THE ABOVE

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**Evaluation of Requirements Specification Media**

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How Do They Match Up with Each other?
Natural Language Prose
Requirements Specification

• Write requirements in "plain English"
• Build upon universal base of understanding of natural language
• Possible to augment with defined terms
• Use of punctuation for clarification
• Text and word processing systems help automate/maintain/alter

Examples:

All input data sets will be terminated with an end of file record
System will respond to service requests within 2 seconds
System will have a friendly user interface
System will never go into an infinite loop

Problem: How to reason about a natural language reqts. spec?
How to determine: completeness, unambiguity, etc.?

Disciplined Use of Natural Language

• Natural response to problems of:
  --imprecision
  --ambiguity
  --consistency (especially when due to size)

• Familiar approaches:
  --Restricted use of defined terms
  --Introduction of structuring (paragraph numbering, outline form, templates, etc.)

• Other, earlier examples of disciplined use of natural language:
  --Legal documents
  --Recipes
Data Base Approaches

- Requirement items stored as database entries
- Queries to retrieve information
- Database tools to check for consistency

PSL (Relational Database Organization)

DESCRIPTION:
this process performs those actions needed to interpret
time cards to produce a pay statement for each hourly employee.;

KEYWORDS: independent;

ATTRIBUTES ARE:
complexity-level high;

GENERATES: pay-statement, error-listing;

RECEIVES: time-card;

SUBPARTS ARE: hourly-paycheck-validation, hourly-emp-update, h-report-entry-generates, hourly-paycheck-production;

PART OF: payroll-processing;

DERIVES: pay-statement;

USING: time-card, hourly-employee-record;

DERIVES: hourly-employee-record;

USING: time-card, hourly-employee-record;

DERIVES: error-listing;

USING: time-card, hourly-employee-record;

PROCEDURE: <<not usually included in a requirements spec.>>

HAPPENS: number-of-payments TIMES-PER pay-period;

TRIGGERED BY: hourly-emp-processing-event;

TERMINATION-CAUSES: new-employee-processing-event;

SECURITY IS: company-only;
Examples:

• Use of structure and reserve words

User interaction functions;

**Timing:** All functions must execute in < 2 seconds

**Subfunctions:**
  - Query
  - Browse
  - Enter

• Disciplined use of naming

  ....**input_value**: pay_rate

  pay_rate: **input_to** ..... 

Hierarchical Decomposition Organization

• Requirements Specification as hypertext

• Structure (DAG) of Requirements Elements
  - Child element represents *part-of* relation

• Requirement Element is a record

• Requirement Element fields carry information as:
  - Instances of preset types
  - Instances related to others by relations
    -- express consistency rules
    -- define consistency determination
    -- define inconsistency remediation
  - Relations among
    -- Requirement elements
    -- Requirement elements and parts of other artifacts
      (e.g., testplan elements, other rqts. representations)
Functional Decomposition Rqts. DAG

Requirement Element: An Example Structure
Example: Using this to specify requirements for a Multifunction Watch

- Watch functions include
  - Telling time
  - Alarms
  - Telephone directory
  - Appointment book
  - Memo pad

- With various additional constraints
  - Speed
  - Accuracy
  - Robustness
  - Etc.

Partial Formalization of Functional Decomposition Requirement Specification

A Requirements Specification, \( R \), is a set
\[ R = \{ r \mid r \text{ is a requirement element} \} \]

\( r \), a requirement element, is a tuple,
\[
\begin{align*}
  r &= ( \text{children}(r), \text{parent}(r), \text{timing}(r), \\
  &\quad \text{functionality}(r), \text{robustness}(r), \\
  &\quad \text{inputs}(r), \text{outputs}(r) )
\end{align*}
\]

ETC.
Intermediate Function Decompositions

Physiology of a Requirement Element

<table>
<thead>
<tr>
<th>NAME</th>
<th>ROBUSTNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DATE</th>
<th>INPUTS</th>
<th>CHILDREN</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>PARENTS</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>LOCAL DATA</th>
<th>TIMING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>FUNCTION DEFINITION</th>
</tr>
</thead>
</table>
Using this for Hierarchy Specification

children(r) = \{s \in R \mid s \text{ is a subfunction of } r\}

Question: What do we mean by “subfunction”?
-- Is included textually within
-- Requires in order to execute properly
  (i.e. is a module that is used)
-- ??

parent(r) = The s \in R such that r \in children(s)

ancestors(r) = the transitive closure of r under the parent relation
  = r \cup \text{parent}(r) \cup \text{parent}(\text{parent}(r)) \cup ….

Timing Requirement Specification

timing(r) is a Boolean function

Intuition: To help clarify, define timing(r) to be the function pass_r(testresult), which maps the set of results of executing testcases for r onto the Boolean values \{True, False\}

Thus, pass_r is a function that defines what it means for a testresult to “pass” (i.e. to satisfy a timing constraint)

Examples: timing(datebook) =
  \text{pass}_{datebook}(testresult) = testresult < 0.1 \text{ seconds}
  \text{pass}_{datebook}(testresult) = testresult < \quad 0.1 + \text{size(datebook_cont)}/1000

Note obvious proximity to testing concerns
Functionality Specification

functionality(r) = n, a node in a graph, G

Intuition: The functionality being specified here is being specified with the help of a graph, whose semantics provide rigor to the definition of the function being required.

The semantics of the graph will turn out to be vitally important in supporting reasoning about the requirements specification and its consistency with design specifications.

Using a DFD

functionality(r) = n, a node in the DFD, D = (N, E)

Intuition: The functionality being specified here is being specified with the help of a DFD.
Input/Output Specification

inputs(r) = { i | i is an object needed for the execution of the function denoted by n, the DFD node used to define the functionality of r }

outputs(r) = { o | o is an object created by the execution of the function denoted by n, the DFD node used to define the functionality of r }
An FSM can help too

• Use FSM to define how a (set of) function(s) must be related to others.
• Create an “Accessed By” field?
• Value is a pointer into FSM that describes the workings of the system
Each node (state) pointed to by the appropriate field in the appropriate node of the requirements definition.

Children of these nodes point to these “substates”.
Multirepresentation Systems

- Have seen that different representations are of different uses
- One diagram may be useful in different ways to different stakeholders
- But most stakeholders require a variety of diagrams
- Several different diagrams can be expected to be needed to satisfy the different stakeholders
- Problems with different views/diagrams
  - Are they all representing the same software product?
  - How to assure that they are all consistent with each other?
  - If the product changes, then ALL views must change correspondingly

STATEMATE supports Requirements Specification

- Key feature is maintenance of consistency among views
  --Done by projecting views of abstract model
  --Change abstract model through changes to views
- Use of Hierarchical Decomposition for understandability
- Different diagrammatic views
  --Statecharts (Enhanced FSMs)
  --Enhanced Data Flow Diagrams
- Statecharts, FSMs both support specification of different requirements types simultaneously
  --Functional
  --Robustness
  --Safety
Statechart

- **Initialize**: do: Initialize course object
- **Unassigned**: do: Assign professor to course
- **Open**: entry: Register a student
  - do: Assign professor to course
  - addStudent/numStudents > 3
- **Closed**: do: Report course is full
- **Canceled**: do: Send cancellation notices
- **RegistrationComplete**: do: Generate class roster
  - numStudents = 10

Statechart with Nested States

- **Initialize**: do: Initialize course object
- **Unassigned**: do: Assign professor to course
  - addStudent/numStudents = 0
  - cancelCourse
  - registration closed/numStudents < 3
- **Open**: entry: Register a student
  - addStudent
  - [ numStudents = 10 ]
  - registration closed/numStudents > 3
- **Canceled**: do: Send cancellation notices
- **Closed**: do: Report course is full
- **RegistrationComplete**: do: Generate class roster
  - [ numStudents = 10 ]
Robustness Specification

\[ \text{robustness}(r) = \text{a first order logic implication} \]
\[ A_r \implies B_r \text{ such that whenever an execution of the functionality defined by } r \text{ “satisfies” the predicate } A_r, \text{ then it necessarily also “satisfies” the predicate } B_r. \]

Example:  
\[ A_r: \text{The clock stops ticking} \]
\[ B_r: \text{The datebook keeps working} \]

Security Specification

- Who is allowed to use this function?  
- Under what circumstances?  
- With what restrictions?  
- Etc.
Some Possible Relations Involving Such Nodes

Robustness Spec. Incorporated into System Test Plan

Parents of Children = Children of Parents

Speed of Children > Speed of Parents

Parents of Children = Children of Parents

Data object also used in a DFD

Functionality related to testcase inputs/outputs

same function as one in a DFD

This Diagram Suggested When to Check

Define Reqmt Element

Define Functional

Define Input/Output

Make Functional

Make Input/Output

Define Functional

Define Input/Output

Define Functional

I/O OK

I/O OK

I/O OK

I/O OK
Examples of what to check and how

Internal Consistency:
\[ \forall r \in R, s \in \text{children}(r) \Rightarrow \text{parent}(s) = r \]

\[ \forall r \in R, \forall \text{testresult}, \text{pass}_r(\text{testresult}) = \text{True} \Rightarrow \text{pass}_s(\text{testresult}) = \text{True} \forall s \in \text{descendant}(r) \]

Interartifact Consistency:

\[ \forall r \in R, i \in \text{inputs}(r) \Rightarrow i \text{ is an input to the node } n \text{ in the DFD that defines the functionality of } r \]
Checking Timing Requirements Against Design (a look ahead)

Showing consistency between a timing requirement, and timing characteristics of a design specification:

Suppose design is specified by a flowgraph; flowgraph is defined by means of the Immfoll relation. Use Immfoll to derive the Fol relation.

Suppose each flowgraph node is annotated with a timing specification. Suppose requirements node is defined by one or more flowgraph nodes.

Trace flowgraph paths to compute timing of function, and compare to requirement node timing spec.
Checking Timing Requirements

Other Requirements Structures

- Functional decomposition often works well as the structure of a requirements specification
  - Key feature: “all” requirements are clustered by function
- Other decompositions are sometimes better
- Goal decomposition is increasingly interesting
- vanLamsweerde’s KAOS system
  - Goals decomposed into subgoals
  - Special attention to robustness with scoped exception specification
Another One: Tokeneer

Security Decomposition

- Focus on who can do what
- Hard to infer that from the functional decomposition
- Makes most sense when security is the key focus of the system
- May make it harder to infer other things
  - Presumably they are less important
(Recall) Typical Stakeholders
and their Needs

- Customer: needs to
  - communicate what the system must be like
  - have a basis for determining if it works right
- Developer: needs to
  - understand what the system must be like
  - what the design must implement
- Tester: needs to
  - know how to evaluate the final system
- User: needs to
  - see that real underlying needs are going to be met

Evaluate These Requirement Specification Approach Against Requirements Problems

- Incompleteness
- Inconsistency
- Ambiguity
- Infeasibility
- Unevenness
- There are others....
Requirements Incompleteness

- **EXAMPLES:** Missing requirements, missing details
- **CAUSES**
  - Customer may be unavailable, inaccessible, a group
  - Customer asks for too little
    - doesn't understand computer's capabilities
    - doesn't understand interfaces to larger system
  - Customer doesn’t think of *everything*
    - desired function not mentioned
    - special case forgotten
  - The world changes, new things are required
- **REMEDIAL APPROACHES**
  - Cross checking requirements with each other
  - Facilitated by building in relations and redundancy

Requirements Inconsistency

- **Many types of inconsistency:** inconsistent wrt what?
  - Timing: function/subfunction mismatch
  - Functionality: subfunctions don’t “flow right”
  - Robustness: no specification of error recovery
- **CAUSES**
  - Customer may be a group that disagrees
  - Different people may negotiate different parts
  - Early identification of inconsistency can be a big benefit
- **REMEDIAL APPROACHES**
  - “Cross-checking” related requirements elements’
    - What to check against what? How? For what?
Requirements Ambiguity

- More than one possible set of inferences

CAUSES
- Customer may be a group where no one sees the whole picture—at least at first
- Difficult to spot ambiguity in large, complex applications
- So many parts, related to each other in so many ways

REMEDIAL APPROACHES
- Materialize the relations
- Use them to identify inconsistencies

PROBLEM: How to control which inferences are possible, and which are not allowable?

Requirements Infeasibility

- CAUSES
  - Customer asks for too much
    » no conceivable algorithm
    » unrealistic requests
  - Still useful to know what ultimate desires are
    » Enables early expectation management
    » Suggests incremental development planning

REMEDIAL APPROACHES
- This is a very hard problem
- Need to determine consistency of requirements specification with designs and implementations
- Multiple notions of “consistency”
Requirements Unevenness

• CAUSES
  – Different sources of information
  – Different people write different parts
  – Different parts of specification are more difficult than others
• REMEDIAL APPROACHES
  – Relate details at different levels to other details at similar levels