CAS 741, CES 741 (Development of Scientific Computing Software)

Fall 2019

05 Program Families

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Program Families

- Administrative details
- Questions?
- Finish up on SRS
- Specification Qualities
- Motivation
- Proposed Family Methods
- Family of Mesh Generators
- Family of Linear Solvers
- Family of Material Behaviour Models

Administrative Details

- Presentations
  - VGA by default, ask if need adapter
  - Can use my laptop, but track pad is difficult to use
- Repos.xlsx
- Domain experts - volunteers?
- 80 columns in tex files
- CA template now updated

Administrative Details: Report Deadlines

SRS	Week 06	Oct 7
System VnV Plan	Week 08	Oct 28
MG + MIS	Week 10	Nov 25
Final Documentation	Week 14	Dec 9

- The written deliverables will be graded based on the repo contents as of 11:59 pm of the due date
- If you need an extension, please ask
- Two days after each major deliverable, your GitHub issues will be due
- Domain expert code due 1 week after MIS deadline

Administrative Details: Presentations

SRS Present	Week 05	Week of Sept 30
Syst. VnV Present	Week 07	Week of Oct 21
MG + MIS Syntax Present	Week 9	Week of Nov 4
MIS Semantics Present	Week 11	Week of Nov 18
Unit VnV or Impl. Present	Week 12/13	Week of Nov 28

- Informal presentations with the goal of improving everyone's written deliverables
- Domain experts and secondary reviewers (and others) will ask questions

Administrative Details: Presentation Schedule

- SRS (or CA) Present
  - **Monday: Deema, Sharon, Bo**
  - **Thursday: Sasha, Colin, Zhi**
- Syst V&V Plan Present
  - Monday: Deema, Peter
  - Thursday: Sharon, Ao
- MG + MIS Syntax Present
  - Monday: Deema, Bo
  - Thursday: Colin, Sasha
- MIS Syntax + Semantics Present
  - Monday: Zhi, Peter
  - Thursday: Sharon, Ao
- Unit VnV Plan or Impl. Present
  - Monday: Bo, Sasha, Colin
  - Thursday: Zhi, Peter, Ao

Questions?

- Questions about SRS?
- Any questions on the SRS Checklist?
- Is $a = \frac{dv}{dt}$ a TM or a DD?

Kreyman and Parnas Five Variable Model

- See [?]
- An alternative approach
- Unfortunately the numerical algorithm is not hidden in the requirements specification
- The analogy with real-time systems leads to some confusion

Examples

- Solar Water Heating System
- GlassBR

Specification Qualities

- What are the important qualities for a specification? What makes a specification a good specification?

Specification Qualities

- The qualities we previously discussed (usability, maintainability, reusability, verifiability etc.)
- Clear, unambiguous, understandable
- Consistent
- Complete
  - Internal completeness
  - External completeness
- Incremental
- Validatable
- Abstract
- Traceable

Summarized in [14, p. 406]

Clear, Unambiguous, Understandable

- Specification fragment for a word-processor
  - Selecting is the process of designating areas of the document that you want to work on. Most editing and formatting actions require two steps: first you select what you want to work on, such as text or graphics; then you initiate the appropriate action.
- What are the potential problems with this specification?

Clear, Unambiguous, Understandable

- Specification fragment for a word-processor
  - Selecting is the process of designating areas of the document that you want to work on. Most editing and formatting actions require two steps: first you select what you want to work on, such as text or graphics; then you initiate the appropriate action.
- What are the potential problems with this specification?
  - Can an area be scattered?
  - Can both text and graphics be selected?

Clear, Unambiguous, Understandable

- Specification fragment from a real safety-critical system
  - The message must be triplicated. The three copies must be forwarded through three different physical channels. The receiver accepts the message on the basis of a two-out-of-three voting policy.
- What is a potential problems with this specification?

Clear, Unambiguous, Understandable

- Specification fragment from a real safety-critical system
  - The message must be triplicated. The three copies must be forwarded through three different physical channels. The receiver accepts the message on the basis of a two-out-of-three voting policy.
- What is a potential problems with this specification?
  - Can a message be accepted as soon as we receive 2 out of 3 identical copies, or do we need to wait for receipt of the 3rd

Unambiguous, Validatable

- Specification fragment for an end-user program
  - The program shall be user friendly.
- What is a potential problems with this specification?

Unambiguous, Validatable

- Specification fragment for an end-user program
  - The program shall be user friendly.
- What is a potential problems with this specification?
  - What does it mean to be user friendly?
  - Who is a typical user?
  - How would you measure success or failure in meeting this requirement?

Unambiguous, Validatable

- Specification fragment for a linear solver
  - Given A and b, solve the linear system $Ax = b$ for x, such that the error in any entry of x is less than 5 %.
- What is a potential problems with this specification?

Unambiguous, Validatable

- Specification fragment for a linear solver
  - Given A and b, solve the linear system $Ax = b$ for x, such that the error in any entry of x is less than 5 %.
- What is a potential problems with this specification?
  - Is A constrained to be square?
  - Can A be singular?
  - Even if the problem is made completely unambiguous, the requirement cannot be validated.

Consistent

- Specification fragment for a word-processor
  - The whole text should be kept in lines of equal length. The length is specified by the user. Unless the user gives an explicit hyphenation command, a carriage return should occur only at the end of a word.
- What is a potential problems with this specification?

Consistent

- Specification fragment for a word-processor
  - The whole text should be kept in lines of equal length. The length is specified by the user. Unless the user gives an explicit hyphenation command, a carriage return should occur only at the end of a word.
- What is a potential problems with this specification?
  - What if the length of a word exceeds the length of the line?

Same Symbol/Term Different Meaning

- Can you think of some symbols/terms that have different meanings depending on the context?

Consistent

- Language and terminology must be consistent within the specification
- Potential problem with homonyms, for instance consider the symbol σ
  - Represents standard deviation
  - Represents stress
  - Represents the Stefan-Boltzmann constant (for radiative heat transfer)
- Changing the symbol may be necessary for consistency, but it could adversely effect understandability
- Potential problem with synonyms
  - Externally funded graduate students, versus eligible graduate students, versus non-VISA students
  - Material behaviour model versus constitutive equation

Complete

- Internal completeness
  - The specification must define any new concept or terminology that it uses
    - A glossary is helpful for this purpose
- External completeness
  - The specification must document all the needed requirements
    - Difficulty: when should one stop?

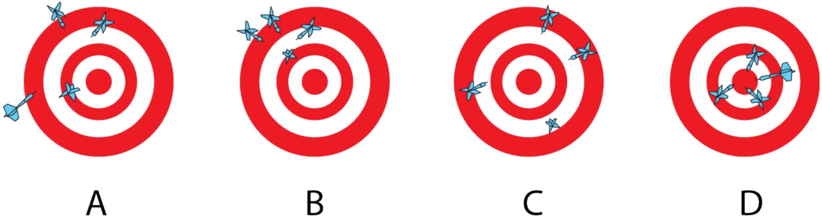
Incremental

- Referring to the specification process
  - Start from a sketchy document and progressively add details
  - A document template can help with this
- Referring to the specification document
  - Document is structured and can be understood in increments
  - Again a document template can help with this

Traceable

- Explicit links
  - Within document
  - Between documents
- Use labels, cross-references, traceability matricies
- Common sense suggests traceability improves maintainability
- Shows consequence of change
- Minimizes cost of recertification
- Additional advantages
  - Program comprehension
  - Impact analysis
  - Reuse
- Why is traceability important?

Accuracy Versus Precision



What is the distinction between accuracy and precision?

Program Family Examples

Program Families

- Can think of general purpose (or multi-purpose) SC software as a program family
- Some examples of physical models are also appropriate for consideration as a family
- A program family is a set of programs where it makes more sense to develop them together as opposed to separately
- Analogous to families in other domains
  - Automobiles
  - Computers
  - ...
- Need to identify the commonalities
- Need to identify the variabilities
- Discussed in general in [4, 10]

Background

- Program family idea since the 1970s (Dijkstra, Parnas, Weiss, Pohl, ...) - variabilities are often from a finite set of simple options [8, 9, 6]
- Families of algorithms and code generation in SC (Carette, ATLAS, Blitz++, ...) - not much emphasis on requirements [3, 23, 19, 2]
- Work on requirements for SC
  - Template for a single physical model [16, 15]
  - Template for a family of multi-purpose tool [11, 13, 12]
  - Template for a family of physical models [18, 17, 7]

Motivation

- Requirements documentation
  - Allows judgement of quality
  - Improves communication
    - Between domain experts
    - Between domain experts and programmers
    - Explicit assumptions
    - Range of applicability
- A family approach, potentially including a DSL to allow generation of specialized programs
  - Improves efficiency of product and process
  - Facilitates reuse of requirements and design, which improves reliability
  - Improves usability and learnability
  - Clarifies the state of the art

Advantages of Program Families to SC?

- Usual benefits
  - Reduced development time
  - Improved quality
  - Reduced maintenance effort
  - Increased ability to cope with complexity
- Reusability
  - Underused potential for reuse in SC
  - Reuse commonalities
  - Systematically handle variabilities
- Usability
  - Documentation often lacking in SC
  - Documentation part of program family methodology
  - Create family members that are only as general purpose as necessary
- Improved performance

Is SC Suited to a Program Family Approach?

Based on criteria from Weiss [1, 21, 22, 5, 20]

- The redevelopment hypothesis
  - A significant portion of requirements, design and code should be common between family members
  - Common model of software development in SC is to rework an existing program
  - Progress is made by removing assumptions
- The oracle hypothesis
  - Likely changes should be predictable
  - Literature on SC, example systems, mathematics
- The organizational hypothesis
  - Design so that predicted changes can be made independently
  - Tight coupling between data structures and algorithms
  - Need a suitable abstraction

Challenges

1. Validatable
   - Requirements can be complete, consistent, traceable and unambiguous, but still not validatable
   - Input and outputs are continuously valued variables
   - Correct solution is unknown a priori
   - Given $dy/dt = f(t, y)$ and $y(t_0) = y_0$, find $y(t_n)$
2. Abstract
   - If too abstract, then difficult to meet NFRs for accuracy and speed
   - Assumptions can help restrict scope, but possibly as much work as solving the original problem
     - $Ax = b$
     - $x^T Ax > 0, \forall x$
   - Algorithm selection should occur at the design stage

Challenges (Continued)

3. Nonfunctional requirements
   - Proving accuracy requirements with a priori error analysis is a difficult mathematical exercise that generally leads to weak error bounds
   - Context sensitive tradeoffs between NFRs can be difficult to specify
   - Absolute quantitative requirements are often unrealistic
4. Capture and Reuse Existing Knowledge
   - Cannot ignore the enormous wealth of information that currently exists
   - A good design will often involve integrating existing software libraries
   - Reuse software and the requirements documentation

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