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What Do Systems Engineers Need To Know About Software?

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Tutorial agenda

Overview

- Purpose of tutorial
- Attitudes
- What are software and hardware? What are systems and software engineering? How are they similar and different?

Vocabulary

Some specific software knowledge for systems engineers

Example concerns: Safety and security

The future: A partnership

Conclusion

Purpose: Systems engineers understand…

How does software differ from hardware?

How does software engineering differ from systems engineering?

Basic software terms and concepts not always clear to systems engineers

Approach for the future: Partnership

Note: SW = Software, SWE = Software engineer(ing),

SysE = Systems engineer(ing)

Attitudes … correct?

SysEs think:

- Software engineers think only in bits and bytes
- Software engineers don't recognize that anything is important other than software or logic that will become software
- Software engineers are subsystem engineers and need to listen to me, because I'm responsible for the larger system

SWEs think:

- Systems engineers act imperious and take credit for the system that software engineering creates
- Systems engineers don't understand what we do, insist on functional software, don't hand over fully complete requirements, …
- "What's the secret sauce that SysEs have that we don't?"
- Systems engineers are a pest…keep trying to make us plan our work, but we do Agile, we can't plan; insist on all requirements up front…

Desired attitude re systems engineering

We want Software Engineers to see Systems Engineers

- As partners in building a useful complex system
  - Value of each is understood by both
- Primary system responsibility during requirements and validation
- Those to look to for breadth
- Responsible for overall system including “hardware”
- Having complementary expertise

What is software?

- Instructions that turn a general purpose computer into a special purpose computer
- Algorithms
- Computer programs
- The framework on which all capability is built
- The complexity remaining when replacing formerly dedicated (long-lead-time) hardware with generic computer hardware
- All the items needed to provide the user with the functionality they require
  - May include computers, training, backup plans, etc.

Facts about software

Every new software product is unique; otherwise an old one would be copied

Evolving system requirement needs drive software requirements, causing continuing change*

Software provides unprecedented capabilities, but is vulnerable to remote attacks

- Code reuse (bespoke, but also libraries, drivers, vendor products) is desired to save cost, but it is a major source of vulnerabilities

Increasing complexity comes from dynamic program evolution

- Complexity leads to fragility which yields often non-repeatable failures

Testing

- Testing is a horribly inefficient way to find problems to be fixed in poorly written code
- Software testing, including such activities as inspections, are sampling processes

*For software written to solve a real world problem from *Proceedings of the IEEE*, Vol. 68, No. 9, September 1980. "Programs, Life Cycles, and Laws of Software Evolution," by Meir M. Lehman.

Programming laws

Conservation of Organizational Stability

- Invariant Work Rate

Conservation of Familiarity

- Invariant Perceived Complexity

What does software do?

Makes components function, turns components into a system

Provides the glue among other system components (Communication, data)

Four things

- Turns data into information
  - Data from sensors, which view the physical world, e.g.
- Stores data and information
- Makes decisions
  - Enacts algorithms. E.g. decision algorithms.
- Drives actuators
  - to change something in the physical world

Varieties of software

IT vs Embedded systems

- IT: Software that drives only with computer hardware and user interface hardware
- Embedded systems: Software affects the physical world through sensors and actuators

How is it procured?

- Design and build it ourselves
- COTS or GOTS (commercial, or government, off-the-shelf)
- FOSS (Free and open source software)

Two phases

- Development: the fun stuff
- Maintenance: hard. Fixing someone else's code
  - Corrective (bugs), Perfective (new requirements), Adaptive (for changes in databases or operating system), Preventive (reliability…)

What is hardware?

Only software engineers are satisfied with calling a generic group of things “hardware”

It means “not software”

Dictionaries: Hardware

Metal goods and utensils (locks, cutlery, tools, etc.)

(Computers) The sum of all physical objects, such as electrical, mechanical, and electronic devices which comprise a computer system…

Major items of equipment (military equipment; electronic and electrical devices of a vehicle or a computer)

(Military) Weapons, transport, and other physical objects used in conducting a war

Physical objects used in carrying out an activity, in contrast to knowledge, skill, or theory

Weapons, especially handguns, carried on the person, as in: Check your hardware at the door before entering.

What about: “Everything in an airplane other than the software?”

Note: The term “hardware” grates on non-software people

How is software the same as and different from hardware?[1]

For both, design is key
- For software, production is just copying

Much can be automated, e.g. code generation from highly precise design; testing

Myth: Software is easy to change than hardware
- Reality: Yes, for toy problems
- Reality: For real-life problems, changed software is at least as hard as new software
- Reality: For complex systems, software change is probably harder than hardware change (less isolable)

Software becomes fragile when complex: can break it by adding to it.

Software fixes often cause more and worse problems; implications hard to see

Working from your own vs. others' code is different

Aging
- Software, in theory, does not get old: No corrosion, stress fractures etc.
- But: Patches, re-working to work with changing environment. Also lack of support

How is software the same as, and different from, hardware?$_2$

Interfaces. Software interfaces are 100% under the control of the software designer and programmer: Mistakes can be made

- In contrast, physical interfaces (structural, electrical, fluid) are to a great deal determined by nature (and by previous designers' decisions, i.e. of parts)
- Note: for reused/OTS software: to some extent these are also determined by previous designers' decisions

Hard to keep track of how software is used

- Copied easily
- Aftermarket applications
- IT vendors have to forcefully stop supporting old versions

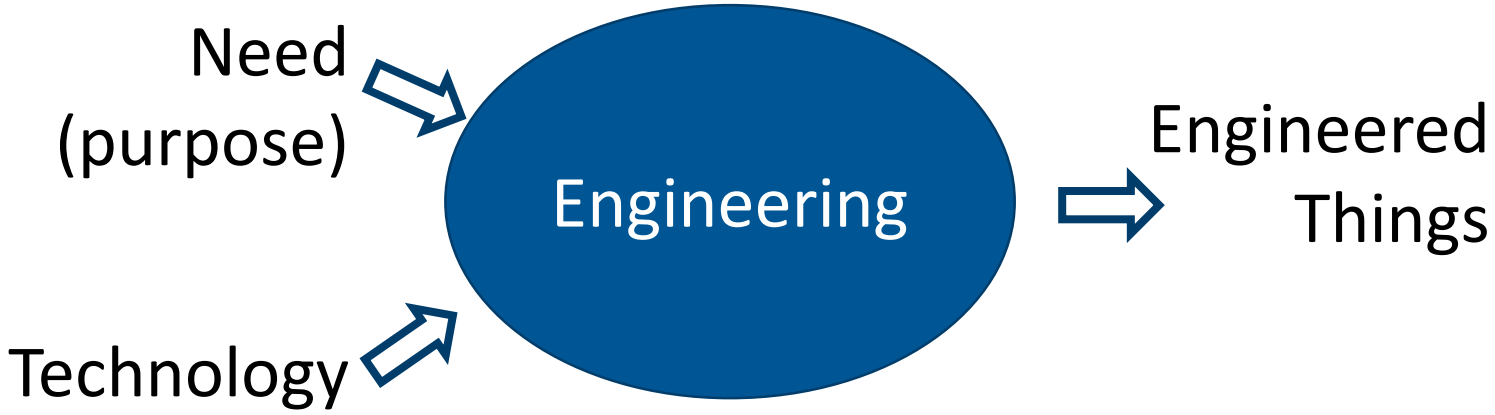
Much use of patterns and styles in software (at least in theory)

What is engineering?

Make things

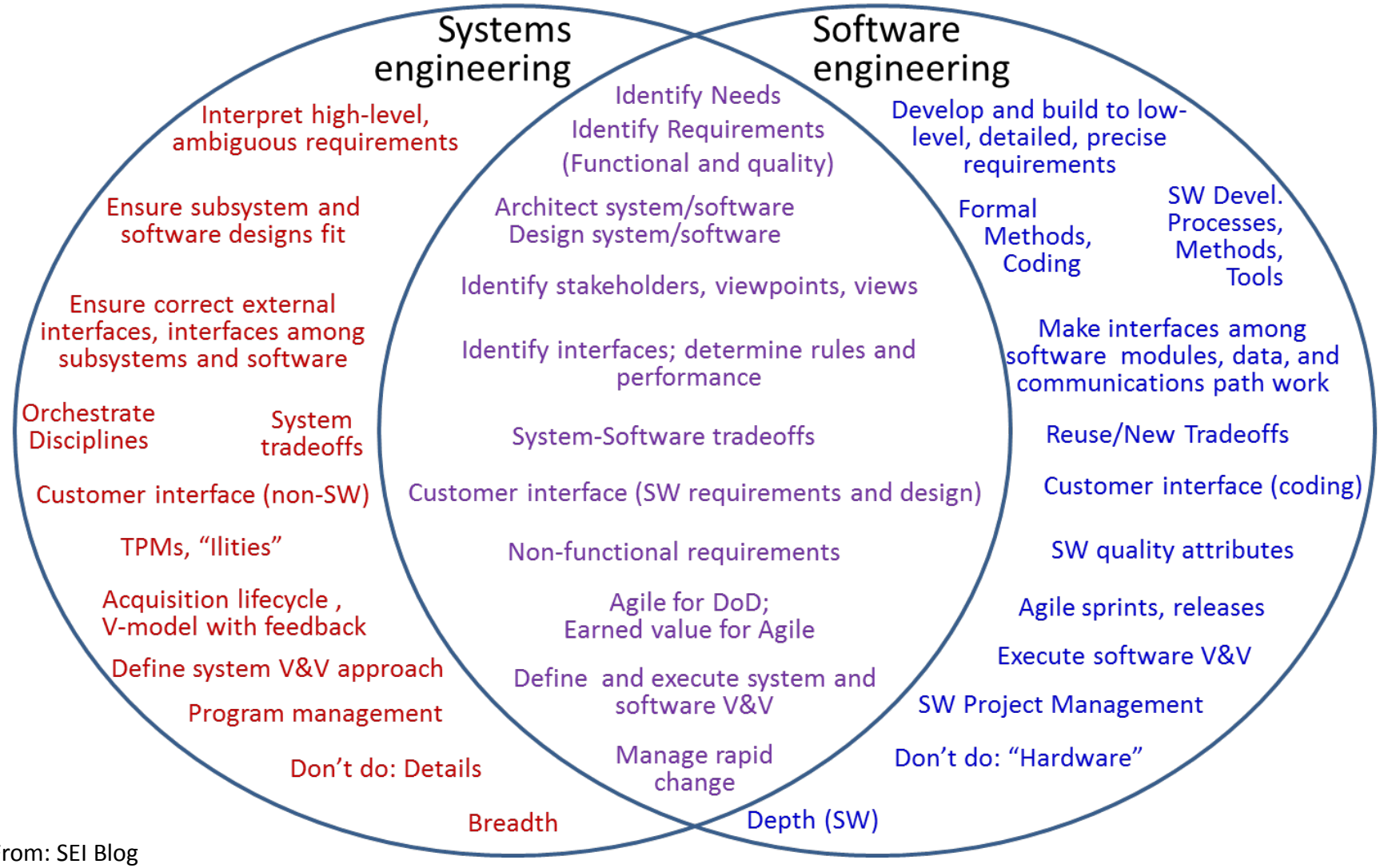
Using technology

For human purposes



☆Does this apply to systems engineering? To software?☆

How are SWE and SysE the same?



From: SEI Blog
https://insights.sei.cmu.edu/sei_blog/2014/05/needed-improved-collaboration-between-software-and-systems-engineering.html

Similarities: software and systems engineering

Both call themselves “SE”!

- Both pursue quality and system usability
- Both have many specialties: one SWE is not replaceable by another SWE any more than a structural systems engineer is replaceable by a data modeler
- Standards have been in the process of harmonizing for 15 years

Interplay of engineering, architecture, management

Evolving: Both more complex, Both turning into systems-of-systems

Both are done in projects

- Hard to estimate
- Very expensive to develop, but increasingly: to maintain
- Delays in one hold up the other

How is software engineering different from systems engineering or specialty engineering?[1]

SW development lifecycle is likely different from physical life cycles

- Don't need long-lead items (except when they do…)
- Acknowledges likelihood of customer desires changing (agility, close customer contact)
- Build-test-build
- "When software is treated as a minor subset of a system, it is likely to become the largest upset"

SW considers functional and non-functional requirements to be different

SW ***requires*** growth capacity

- Most systems have no hardware growth capacity
- Software in any particular instance *must* be changed during life (sustainment=enhancement)
- Any system must have extra processing and memory

How is software engineering different from systems engineering or specialty engineering?$_2$

Verification

- Less variety of testing (i.e. no vibration, thermal); more tests. A hierarchy of component and subsystem tests; integration test, regression test, development test, operational test, inspections
- Vulnerability testing is growing
- Software testing is a sampling process
- Number of possible tests approaches infinity

Configuration management

- All software is intellectual
- SW CM is different from and separate from other CM
- Rigorous, used hourly to daily, and extremely important
  - Identification
  - Change control (i.e. version control)
  - Maintenance (patches, block iterations…)

From literature: "What software managers need to know"

"SW Project Manager is most important role for project success"

Software-specific processes, e.g. code reviews, languages

Strategy development and engagement

Evaluating SWEs

Creating and evaluating effective development teams

Controlling project costs and schedule

Multiple risk assessment and mitigation methods

Computing the confidence level in various cost estimates

Trade studies are imperative

Communication, project planning and scheduling, managing complexity, strategic planning (balanced scorecard, strategy maps, SWOT), Estimating, Cost accounting, Risk management

SWOT = strengths, weaknesses, opportunities, threats

Source: Peters 2015

Tutorial agenda

Overview

Vocabulary

- General technical
- Management related
- Specific technical
- Software “ilities”

Some specific software knowledge for systems engineers

Example concerns: Safety and security

The future: A partnership

Vocabulary$_1$ (technical)

Required attributes – “ilities” → “quality attributes” (non-functional requirements)…things the system must do that can’t be coded in one specific place

Performance – speed of a computer or processor, or effectiveness such as throughput, response time, or availability (narrower than SysE definition: Any key parameter including such things as battery life or antenna gain)

Exception handling – process of responding to exceptions (during computation)…which are anomalous or undesired conditions that may result in faults if not properly handled (x/0, out of memory…)

Refactoring – complete restructuring of a program, usually because as it has been maintained its structure got awkward, without changing its behavior. Changes nonfunctional attributes

Regression testing – testing that software previously shown to be working still is working after changes (including new interfaces with other software)

Vocabulary$_2$ (technical)

Object orientation

- Instead of specifying software in terms of actions and logic, software is organized around real-world objects, with attributes and interactions

Latency – two meanings:

- Latent defects haven't been discovered, but are suspected
- Latency in timing = delay

Entropy (ever-increasing disorder in a system) – two general meanings:

- Software entropy: A computer program that is used will be modified; A modified program will have higher complexity unless specifically addressed; technical debt increases software entropy
- Information entropy: Expected value of information content of a message

Prototyping

- In systems engineering: first version
- In software engineering: partial version

Atomic Requirements – "Leaf" nodes, most detailed requirements

Vocabulary$_3$ (management-related)

Stories/User stories

- Aspects of Agile software development comparable to a scenario or to a number of related requirements – written in sentences

Production – phase where software is rolled out to users

Velocity – In Agile software development, the number of work units (e.g. user stories) completed in a given interval. Assists in estimating the next phase

DevOps – a phase where operational software is being continuously improved (developed): used in Agile software development

Technical debt – a financial metaphor for the work that is not done but is known to be needed when implementing a short term solution to a problem. The additional work that must be done long-term

Vocabulary$_4$ (specific technical)

Backplane: a hardware board that provides connections among main computer circuit boards

SQL and NOSQL

- Structured Query Language: Programming language developed for managing data in a relational database
- No (or: Not Only) SQL: a database management system consisting of objects other than tables in relational databases (can deal more rapidly with a variety of data structures)

Jira, GitHub etc…Tools used in SW development (specifically: proprietary issue tracking product, software repository hosting service)

Vocabulary$_5$ software “ilities”

SW architecture is largely driven by **non-functional requirements** (ilities) = “quality attributes”

Design qualities* (“conceptual integrity,” maintainability, reusability*)
Run-time qualities* (availability, interoperability, manageability,* performance, reliability, scalability,* security)
System qualities* (supportability, testability)
User qualities* (usability); also modifiability

Reliability issues based on bugs, or unintended interactions, not mechanical failures

Redundancy doesn’t solve **vulnerability** problems. If a flaw disables one helicopter, it’ll disable the second one too

*Kaniss, Al. What is a software engineer, CrossTalk May/June 2015

Tutorial agenda

Overview

Vocabulary

Some specific software knowledge for systems engineers

- Basic software engineering principles
- Evolution
- Paradigms and styles
- Defects
- Lean/Agile/SAFe
- Formal methods

Example concerns: Safety and security

The future: A partnership

Basic software engineering principles*

- Intellectual Control
- Divide and Conquer
- Identify the customers
- Fuzzy into Focus
- Document it
- Essence of software is input-output
- Too much engineering is not good
- Plan for change
- Reuse as possible (not just code!)
- Keep simple: Cyclomatic complexity** <30

Also services, e.g. Cloud, software-as-a-service

Sources: *Hamlet and Maybee 2001. The Engineering of Software: Technical Foundations for the Individual. Addison Wesley. Chapter 2, pp. 31-64.
** http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication500-235.pdf (1996)

Evolution

Requirements for software are always changing

- System requirements changes often end up in software
- Easiest way to implement a new capability
- Threats, operating systems, interfacing software change
- Mental models change (User interface)

Evolving programs cause increasing complexity; causes fragility = unrepeated failures

Paradigms*

Classify languages and programs

E.g., structured, object-oriented, aspect-oriented, agent-oriented, functional, process-oriented

Imperative, functional, logic, object-oriented**

Event-driven, service-oriented, time-driven

Sequential vs parallel computing

Functional vs procedural languages

Applications, such as robotics, machine-learning

Modular vs monolithic, structured vs non-structured (array)

*Good source: http://cs.lmu.edu/~ray/notes/paradigms/
**Source: http://people.cs.aau.dk/~normark/prog3-03/html/notes/paradigms_themes-paradigm-overview-section.html

Architecture Styles

Architecture style	Description
Client/Server	Segregates the system into two applications, where the client makes requests to the server. In many cases, the server is a database with application logic represented as stored procedures.
Component-Based Architecture	Decomposes application design into reusable functional or logical components that expose well-defined communication interfaces.
Domain Driven Design	An object-oriented architectural style focused on modeling a business domain and defining business objects based on entities within the business domain.
Layered Architecture	Partitions the concerns of the application into stacked groups (layers).
Message Bus	An architecture style that prescribes use of a software system that can receive and send messages using one or more communication channels, so that applications can interact without needing to know specific details about each other.
N-Tier / 3-Tier	Segregates functionality into separate segments in much the same way as the layered style, but with each segment being a tier located on a physically separate computer.
Object-Oriented	A design paradigm based on division of responsibilities for an application or system into individual reusable and self-sufficient objects, each containing the data and the behavior relevant to the object.
Service-Oriented Architecture (SOA)	Refers to applications that expose and consume functionality as a service using contracts and messages.

Source: https://msdn.Microsoft.com/en-us/library/ee658117.aspx

Layering (architectural pattern or style)

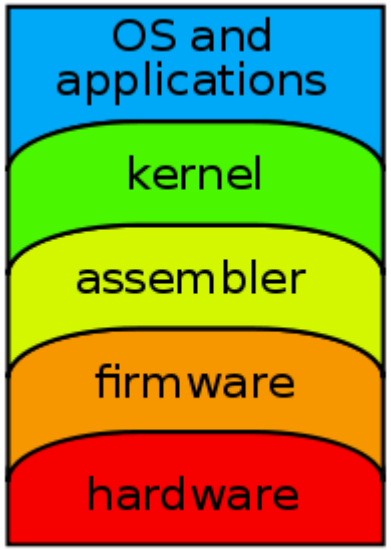
The organization of programming into separate functional components that interact in some sequential and hierarchical way, with each layer usually having an interface only to the layer above it and layer below it

OSI (Open System Interconnection) layered protocols (protocol stack)

TCP/IP Two-layer set of programs: transport and network address functions

Presentation (UI) layer
application layer
business (domain) layer
data access layer

With COTS/FOSS, developing SW = assembling products; maintenance of COTS/FOSS can break system



Layered computer architecture

Source: whatis.techtarget.com/definition/layering
Graphic source: Wikipedia: Abstraction layer

TCP/IP Tranmission control protocol/Internet Protocol
COTS/FOSS: Commercial off the shelf, Free & Open Source Software

Defects$_1$: Why and what

Major indicator of software quality, software process quality, problem reports, software test, readiness…

Qualities: ID number, description, where and how found (date, module, line…, and steps to take to reproduce), version where found, references, person who identified, severity, priority, difficulty of closing, status, who fixed, when closed

Reason: Much less costly to find *in phase created*

Preventing, counting, reducing, managing

Software engineers think in terms of defects: some have a hard time imagining systems engineers *NOT* managing via defects

Entire Agile SW development can be organized around working off defects (Backlog)

Defects$_2$: Relationship to rest of software

How many defects did we find during what phase (usually: what test)? (discovery)

What kind were they? (categorization) Origin, severity, priority, etc.

New programming practices are adopted that reduce creation of defects that escape the “coding” phase into test (e.g. via “strict typing”)

Assigning, scheduling, and fixing defects (resolution) = rework

Testing (verification) esp. regression testing

Closure and reporting

Defects$_3$: Metrics

Number of defects

- Per module, per phase…

Defect rejection ratio: Things originally categorized as defects, but actually were not

Defect leakage (or escape) ratio: fraction of known defects not detected in a phase (often: found later; sometimes using a curve fit to the defect-finding data). “Escape” usually means leaked to next phase without being found

Defects$_4$: Causes

Miscommunication of requirements

- And last-minute changes

Compressed development schedule

Inexperience: Designer, coder, tester

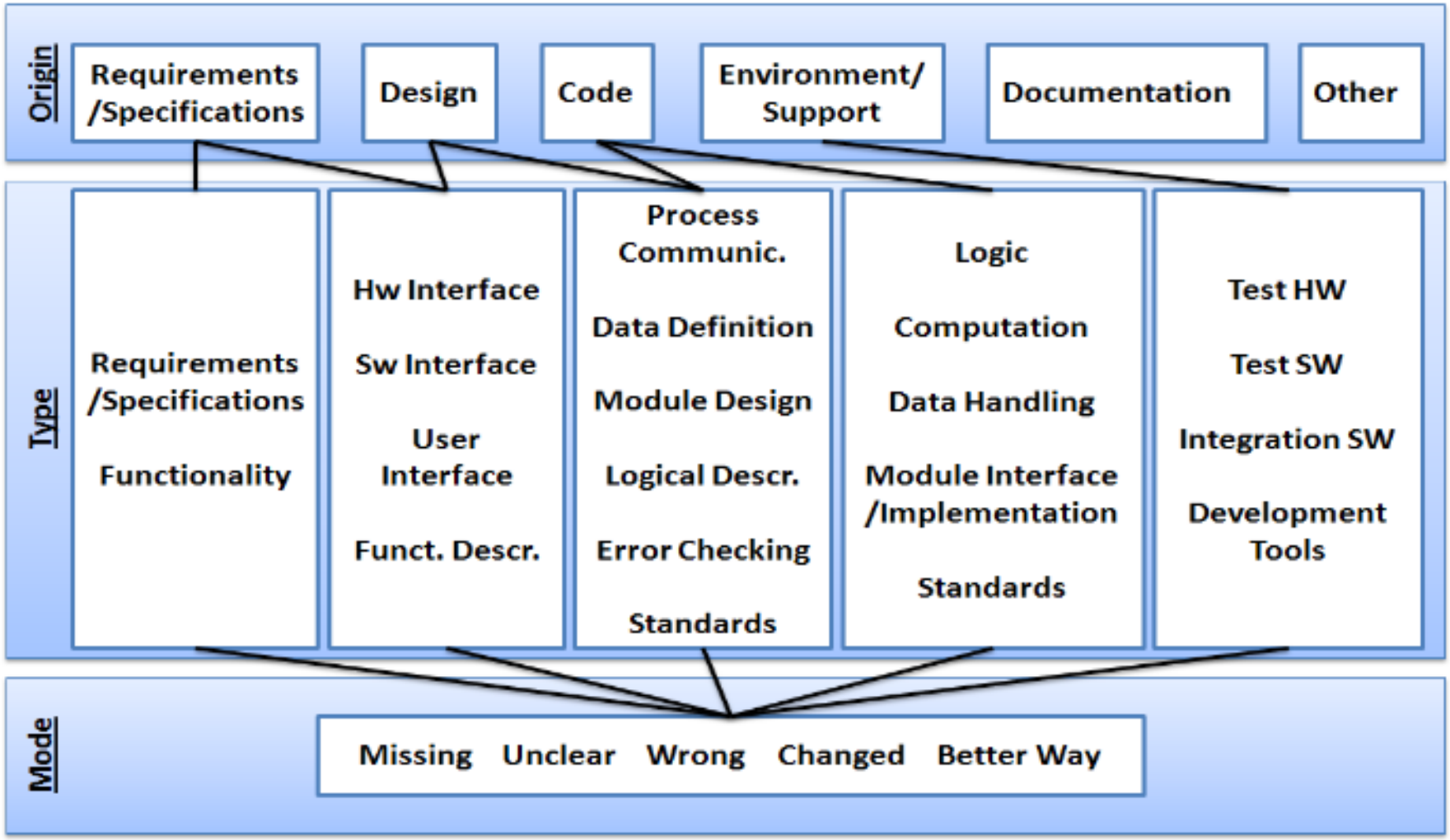
Human error

Version control failure (or lack)

Buggy tools

Source: http://www.softwaretestingclass.com/top-10-reasons-why-there-are-bugs-defects-in-software/

Defects$_5$: Types (for example)



Source: B. Freimut, et al., "An Industrial Case Study of Implementing and Validating Defect Classification for Process Improvement and Quality Management," proceedings of 11th IEEE International Software Metrics Symposium, 2005, as shown in https://web.fe.up.pt/~pro09003/papers/LopesMargarido_ClassificationofDefectTypesinRequirementsSpecifications-ieee.pdf

Defects$_6$: Causal analysis and prevention

Causal analysis: What caused this?

Defect prevention

- Understand causes
- Cost (implications) of having defects
- Cost of implementing prevention (training, tools, procedures, processes)
- Impact on quality

Periodic reviews

- Team, maybe larger groups

Categories:

- Planning
- Requirements, Features ~50%
- Functionality as implemented
- Structural bugs
- Data
- Implementation
- Integration
- Real Time and Operating System
- Test definition/ execution bugs

Lean (2003+)

From lean manufacturing

Mary, Tom Poppendieck

Eliminate waste and improve processes (e.g., Kanban)

Principles

- Eliminate waste
- Amplify learning
- Defer commitment
- Deliver fast
- Empower the team
- Build integrity in
- See the whole

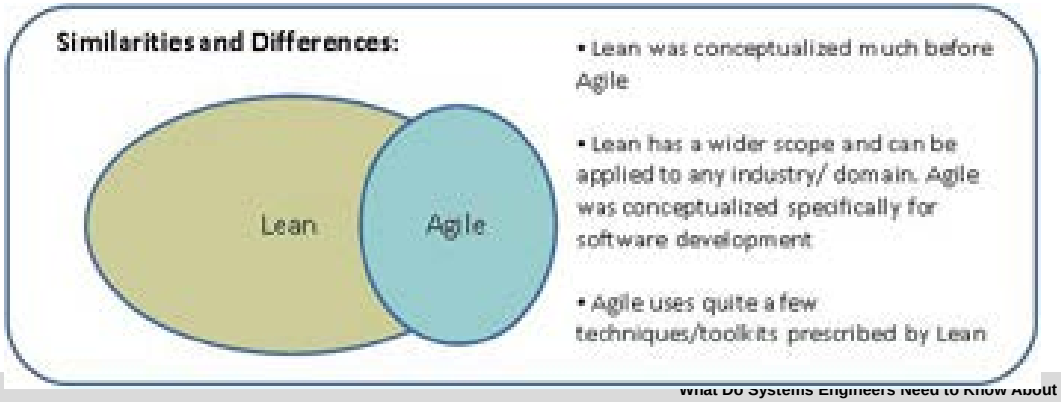
Agile (2001+)

Agile Manifesto (Software community)

Work and deliver incrementally (e.g., Scrum, Extreme Programming, TDD…)

Values

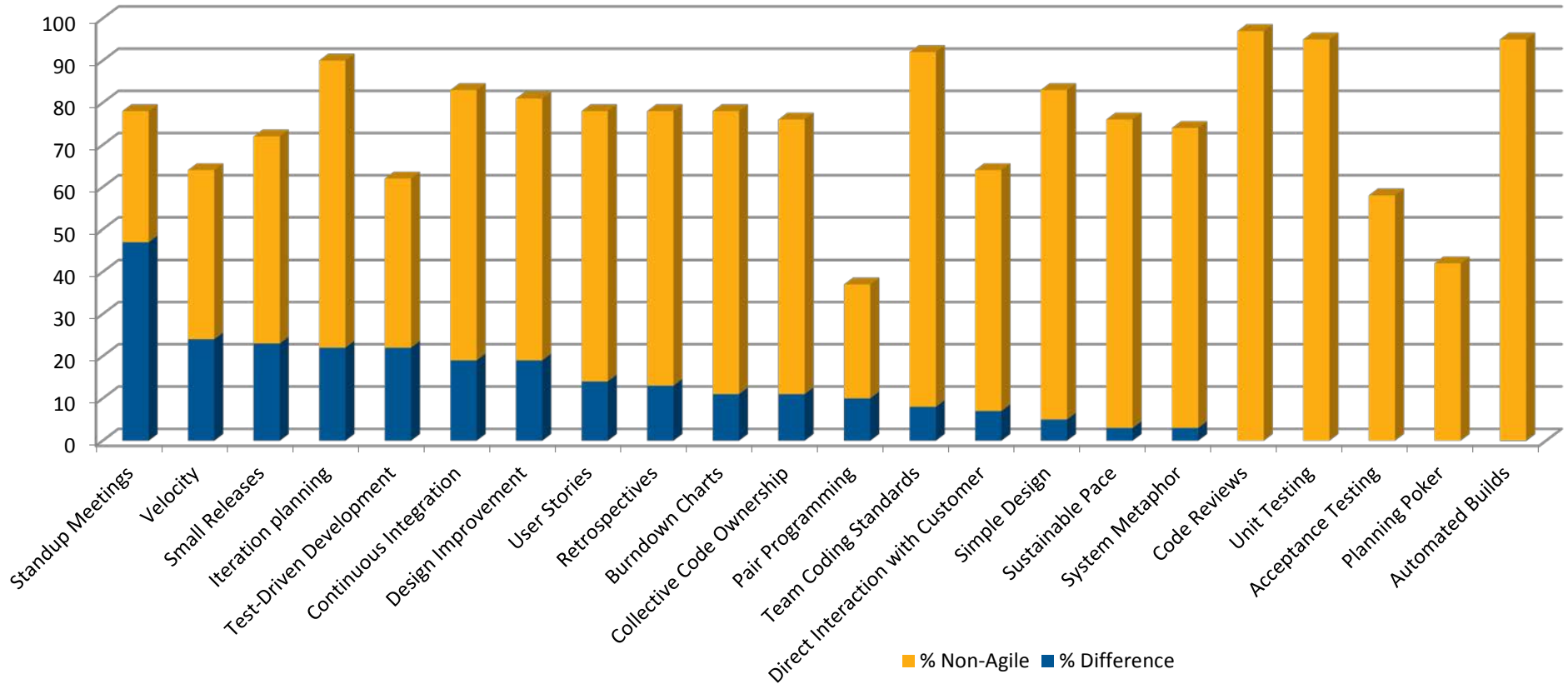
Individuals and interactions over processes and tools
Working software over comprehensive documentation
Customer collaboration over contract negotiation
Responding to change over following a plan



Graphics Source: http://www.processexcellencenetwork.com/ lean-six-sigma-business-transformation

TDD = test-driven development

Agile Methods



Redrew charts in Microsoft article intended to verify practice adoption rates.

Article conclusion: No clear trends in practice adoption

My conclusion: Clear trend that only some practices are performed more often in Agile projects

Source: Murphy, Brendan, et al. "Have agile techniques been the silver bullet for software development at Microsoft?." *2013 ACM/IEEE International Symposium on Empirical Software Engineering and Measurement*. IEEE, 2013.

Scaled Agile Framework SAFe

"Knowledge base for Lean Software and Systems Engineering"

- Proven, codified, and publicly-facing
- Purpose: Scale Agile and lean in larger software enterprises

Principles

- Take an economic view
- Apply systems thinking
- Assume variability; preserve options
- Build incrementally with fast, integrated learning cycles
- Base milestones on objective evaluation of working systems
- Visualize and limit work-in-progress, reduce batch sizes and manage queue lengths
- Apply cadence, synchronize with cross-domain planning
- Unlock the intrinsic motivation of knowledge workers
- Decentralize decision-making

Source: https://www.ivarjacobson.com/scaled-agile-framework

Formal Methods$_1$

System design techniques

Rigorously specified mathematical models of software and hardware systems

- Clarify thinking
- Allow early determination of things that won't work
- Assertions can be proven through *mathematical* proofs of the system design ("regular" test techniques are sampling processes)

Applications

- Formal specification (modeling languages)
- Verification (proving of "theorems" represented by specification; some testing is automated; also model checking)
- Implementation (some can be auto-converted into code)

Concerns: Difficulty (expense), misapplication

Source: https://users.ece.cmu.edu/~koopman/des_s99/formal_methods/

Formal Methods$_2$

Varied examples of formal methods

- Abstract state machines (pseudo code that generates Finate State Machines); model algorithms
- AADL (architecture analysis & design language)
- Knowledge-based software assistant (KBSA; Air Force; 80s)
- Petri nets (modeling language describing state transitions of distributed systems; graphical notation for processes with exact mathematical representation)
- UML (unified modeling language) and SysML (systems modeling language)
- Related items
- MALPAS software static analysis toolset: model checker for formal proof of safety critical systems

Sourc: https://users.ece.cmu.edu/~koopman/des_s99/formal_methods/

Tutorial agenda

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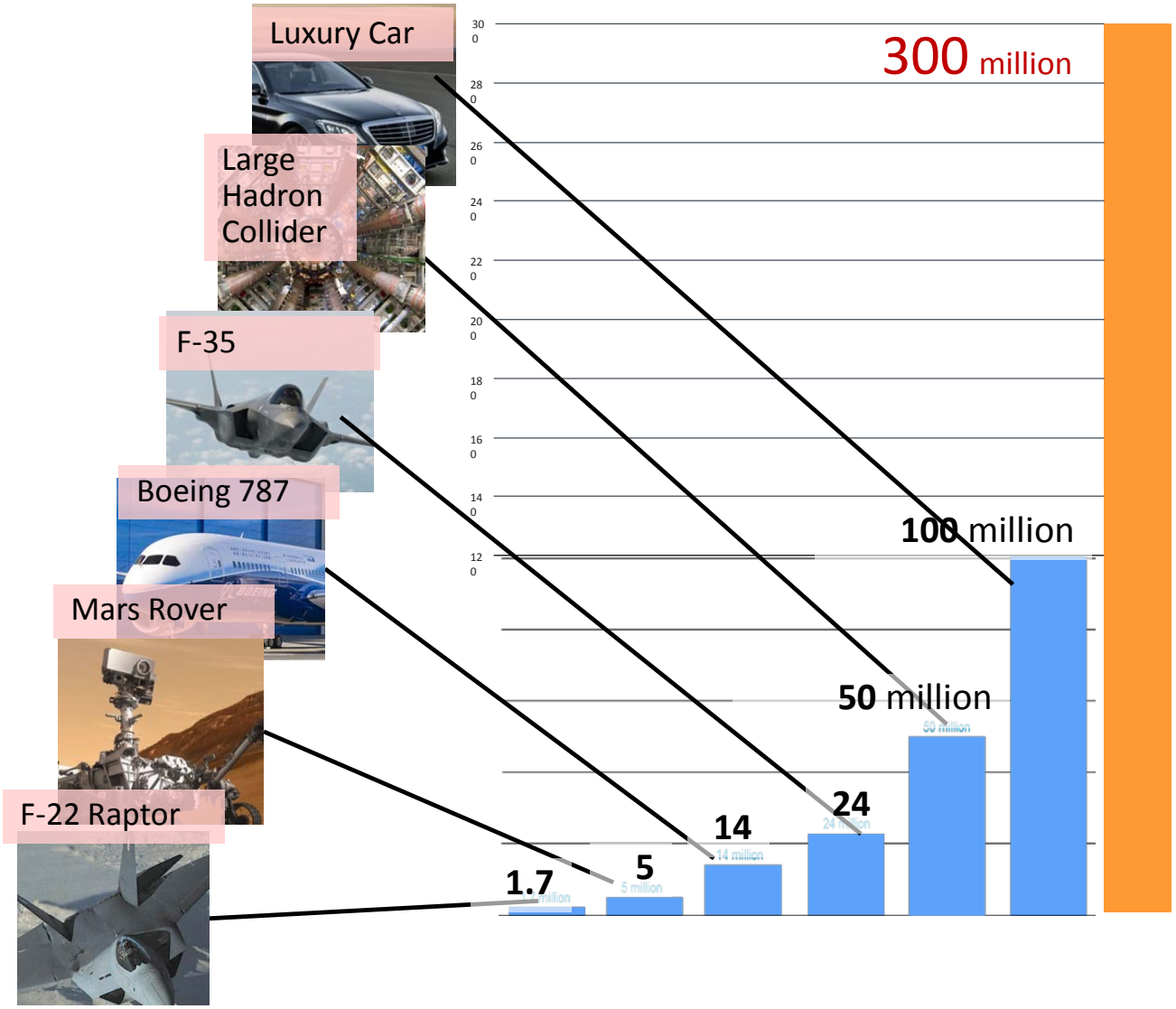
Some specific software knowledge for systems engineers

Example concerns

- Safety (automotive, flight incident)
- Security

The future: A partnership

Automotive: growth in lines of code



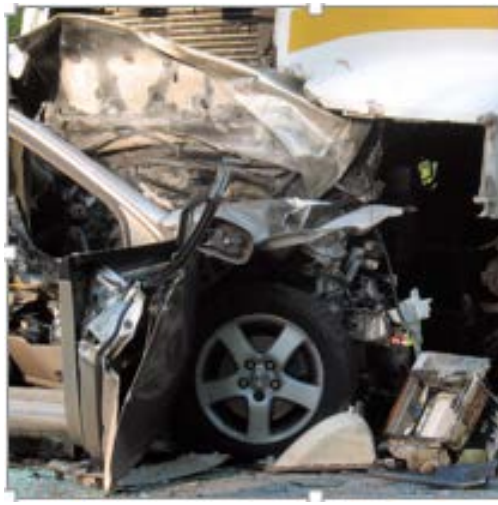
Future cars *will likely be able to communicate with each other, sharing information about traffic hotspots and accidents, and use crash avoidance systems to prevent accidents.*

Toyota unintended acceleration

Toyota paid $1.6B settlement plus $1.2B for concealment re software problems causing cars to speed up uncontrollably

"efforts to conceal the problem and protect its corporate image led to a series of [89] fatalities"

- People? (driver error)
- Hardware? (floor mats? sticky gas pedal?)
- Software? (no error detection/correction code; cascading memory corruptions)



Note: Federal motor vehicle *safety standards not written for software*

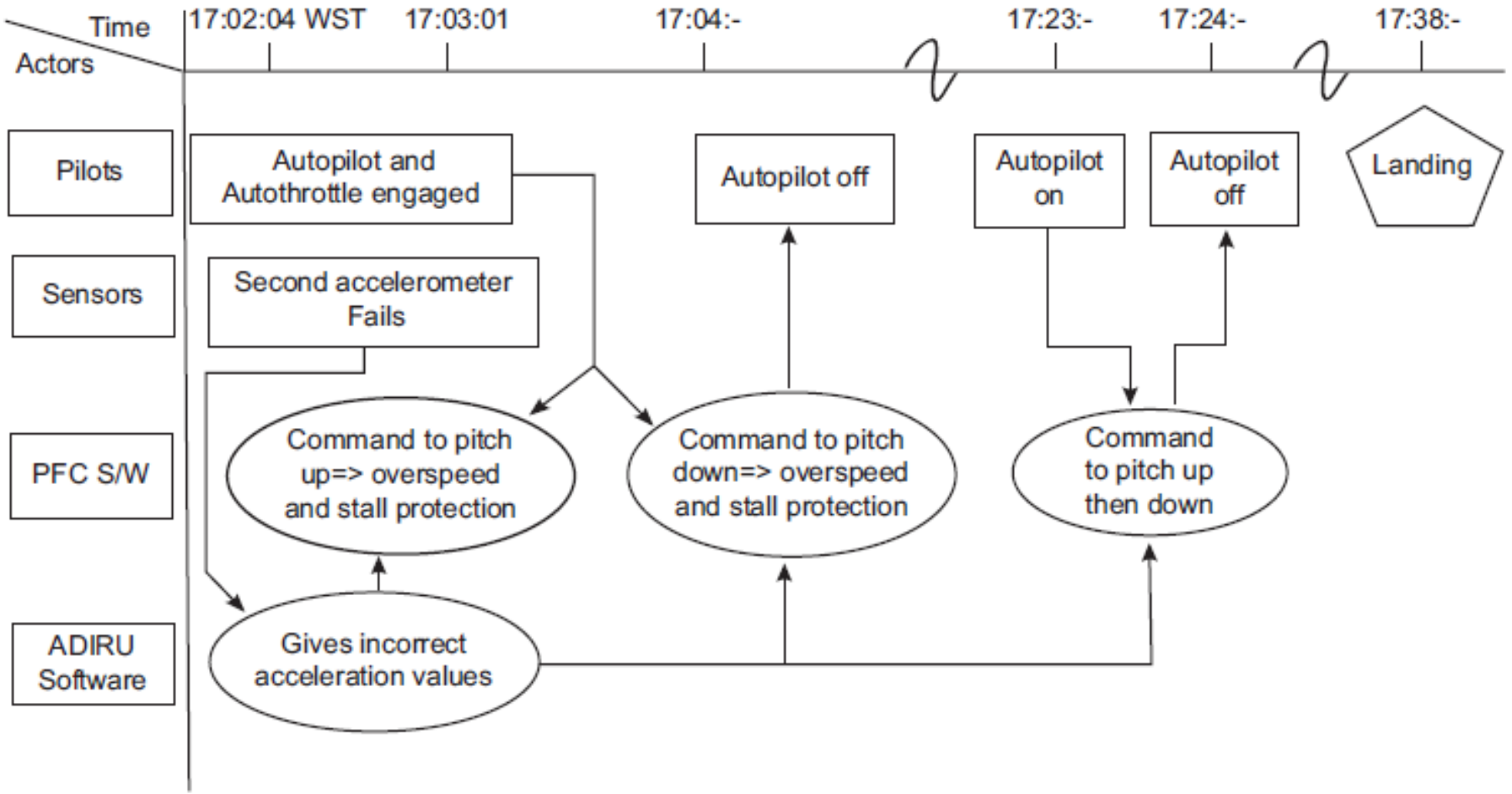
Cyclomatic complexity of "throttle angle function" was 146

should be < 30

Code has 11,000+ global variables (desired: 0)

Sources: http://users.ece.cmu.edu/~koopman/pubs/koopman14_toyota_ua_slides.pdf and https://www.washingtonpost.com/business/economy/toyota-reaches-12-billion-settlement-to-end-criminal-probe/2014/03/19/5738a3c4-af69-11e3-9627-c65021d6d572_story.html

In-flight upset event, Boeing 777-200, Aug 1, 2005



Simulated cockpit video: https://www.youtube.com/watch?v=1XNnEzFF5fg

Security Considerations

These are so critical to system performance, robustness and resilience that we make these particular points separately!

Security

- Software assurance means “free from defects” and “free from vulnerabilities”
- Security processes involve both systems and software
- Software must be free from vulnerabilities that can be exploited by threats that won’t be invented for 5-10 years
- Just about any software can be accessed from just about anywhere on the planet
- Thus, SysE and SwE must evaluate for cybersecurity, from compliances with secure coding practices to actively trying to attack a system as developed, before it is released

Easy to identify and fix with a small patch. Much harder to prove the patched software, under all implementations, remains robust and not vulnerable

Tutorial agenda

Overview

Vocabulary

Some specific software knowledge for systems engineers

Example concerns:

The future: A partnership

- Early involvement
- Trades
- Meetings and estimating
- Communication
- Other
- Help software engineers

Early involvement

Bring in software, especially software architects, before finalizing system architecture

- Explain goal of this phase is not coding, but structuring the software design, giving feedback as to the software issues with the evolving system design, and understanding legacy code usage with its interfacing requirements to new software and security

Up-front software engineering participation means fewer ungrounded assumptions and less re-direction ($\rightarrow$rework, complexity)

During planning, focus on identifying the decisions that need to be made for the project to move ahead

- Then determine SysE and SWE roles in determining information for those decisions

Trades

Identify requirements from various stakeholders as imperatives or tradeables

- De-conflict and implement imperatives; track and trade off tradeables

SysEs do larger-system trade studies, e.g., size weight and power (SWAP); software trades to be planned and done; security is shared

- Software architects must estimate impacts to software of various system decisions
- Share threat models and evaluate attack surfaces jointly

Both SysEs and SWEs are responsible for non-functional (=ilities=quality attributes) and functional requirements. Work together to trade off tradeables

Include software-related requirements (or potential requirements if too early for requirements) and software-related design attributes in system-level trade studies SWE functions more like SysEs of the software (software architects) than programmers

Meetings and estimating

Meetings

- Schedule meetings so that SWEs have blocks of time for concentration (e.g. meetings in 4 half days a week, so they can concentrate in 4-hour blocks and one 8-hour day)
  - Systems engineers almost always multitask, and tend to multitask well. Don't expect SWEs to do it or like it
  - Encourage them to set office hours, then respect them

Estimating

- Remind SWEs that bugs happen and to plan for those. Also, plan for learning, to help re: tendency to underestimate
- Ask, "what might happen that would turn this into a cost and schedule nightmare?" Then estimate and mitigate together

Communication

Keep software informed as to what aspects are known, suspected, or totally guessed, and what is known to be likely to change

- Good SWE encapsulates likely changes so that they won't disrupt the rest of the software being written, or the system

Help them see the context of where the software will run. What is known about it?

Do as much systems engineering as possible using models, e.g. SysML. Keep in mind, there are differences compared to SW and software models. Also, "Model based systems engineering" is not all of systems engineering! for example, coordination

Computer science teaches people how to do small programs. Help SWEs learn what goes into large programs

Other

Use case development

- SysEs must manage use case development (for SW requirements)
- Include abuse and misuse cases (what system must not do)

Testing

- Coordinate system and software tests; durations, purpose, what they determine

“Ilities” roles, especially Security roles

- Together work reliability, availability, maintainability, attributes
- Partner regarding security: what SW vulnerabilities could be leveraged by adversaries to compromise systems (both IT and embedded systems). What priorities on vulnerabilities do system decisions imply?

Appreciation

- Express appreciation no coders/programmers/what SWEs call “Engineers”=builders. Thank them when they turn in code (before the bug reports come in)
- SWEs should appreciate work of SysEs too

Perspective

SWEs recognize they need to know about the domain,

- Generally SysEs have more opportunity to learn a domain, staying with the same program for years and interacting with customers/operators more
- Help SWEs understand, recognizing they are busy learning new languages and techniques, preventing, finding, and resolving bugs, and trying to think creatively through interruptions

Systems engineers are multi-disciplinary; Software engineers may consider themselves multidisciplinary as well: compare domains

SysE and SWE approaches should complement each other for system and program success

Help Software Engineers

Clarify roles

Liaison to other disciplines

Language translation: SW to other and back

Understanding Agile, compare to Lean and other project management

- Example Scaled Agile Framework or SAFe

Tutorial agenda

Overview

Vocabulary

Some specific software knowledge for systems engineers

Example concerns:

The future: A partnership

Conclusion

Systems engineering is responsible for delivering systems that do what they are intended to which are delivered on schedule and within budget

- Ensures the pieces come together into a system

Software engineering allows the delivered systems to do what they are intended to, including interfacing with other systems being Systems engineered

- Ensures the pieces do assigned roles, alone and together

Systems engineering and software engineering are inextricably linked, a relationship that must:

- Begin at the beginning, and
- Continue throughout the life cycle of the program

P. S. What not to do

Say “I used to code”

Say “There is no software at the system level”

Interrupt programmers, or any kind of software engineer, frequently

Think you can “power through” some function better or faster than a computer (such as looking through a data dump for a bad data element)

Think “software reliability is 1”

Think you can get software faster if you throw more people on the project

Say (or think) “software is much easier to change than hardware”

References

Peters 2015: Peters, Lawrence and Ana M. Moreno, 2015. “Educating Software Engineering Managers – Revisited” IEEE/ACM 37th IEEE International Conference on Software Engineering. Florence, Italy. DOI 10.1109/ICSE 2015.168

Sprunck, Markus. (2012) Top 12 things every software engineer should know http://www.sw-engineering-candies.com/blog-1/top10thingseverysoftwareengineershouldknow

What Do Systems Engineers Need To Know About Software?

Backup slides

Programming Languages issues/questions

Choosing a language

Typing (OO, Functional, Declarative, Procedural)

Encapsulation for data abstractions

Run-time checking

Program redundancy checking

Assertions

Problems

Macros

Libraries

Error-prone constructions

Rapid Prototyping

Procedural= C, Cobol, Fortran
OO = Smalltalk, Java, C++
Functional = Erlang, Clojure, F#
Declarative = SQL, XSLT
Multi-paradigm = Python, Java, C++, C#

Software Development Knowledge

Formal Methods
- Specification Languages
- Logic
- Sorting
- Controversy: Formal Methods

Design Notations

Support tools

Object Orientation

Java

DFDs

Testing
- Process
- Coverage testing
- Coverage criteria
- Structural test adequacy

Programming Languages
- Typing
- Encapsulation for data abstractions
- Run-time checking
- Program Redundancy Checking
- Assertions
- Problems
- Macros
- Libraries
- Error-prone constructions
- Choosing a language
- Rapid prototyping

Source: Hamlet and Maybee 2001. The Engineering of Software: Technical Foundations for the Individual. Addison Wesley. Chapter 2, pp. 31-64.

From “Top 12 Things Every SW Engineer Should Know”

1. Fundamentals of emotional intelligence
2. Algorithms and big-O-notation: libraries, individual solutions; analyze others’ code
3. Basics of project management: don’t just estimate code implementation. Recall documentation, security concept, data protection issues, “alignment with worker’s councils, reviews, project management efforts, deployment etc.
4. Mainstream development paradigms
5. Basics about software security: becoming more important
6. Know your development tools and Know the key concepts and underlying technologies of “disciplines”: requirements management, SW & database (DB) design, SW CM, build & deploy, continuous integration, development, debugging, profiling, code analysis, testing. Also infrastructure toolboxes: network monitoring, analysis, pen testing, log file analysis, DB performance tuning

Source: www.sw-engineering-candies.com/blog

From “Top 12 Things Every SW Engineer Should Know”

7. Don’t trust code without adequate test. Even the best programmer needs unit, integration, sys tests; performance and memory tests with real data, static code analysis, code coverage measurement, load & stress tests, peer review
8. Key metrics of SW development…at least, lessons from Agile projects
9. Root cause of the last defect…understand what caused it and how to avoid it
10. Understand the business of your customer. This is one of the systems engineering roles. “If you don’t understand the what, you can’t decide about the how” - Sprunck
11. Understand the infrastructure ITIL language/terminology. Sometimes a developer needs to talk to 5 different infrastructure folks for one question. “The ITIL stuff is the glue among people in infrastructure”
12. Know what you don’t know: Top 118 fundamental elements of SWE
    http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Periodic Table of SW Engineering

Things to know (one chart each follows)

- Requirements
- Design
- Lean IT (Agile)
- Maintenance
- Infrastructure
- Basics
- Implementation
- Code Analysis
- Testing
- Usability
- Tools
- Management
- Soft skills

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Requirements

Requirements elicitation

Requirements analysis

Atomic requirements

Requirements attributes

Requirements reviews?

Traceability management

Management of requirements portfolio

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Design

Component design

Database design

Design patterns

Architecture pattern

Large-scale system design

Design notation

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Lean IT

Scrum, Kanban

Agile methods:

- Agile planning
- Pair Programming
- Test-driven development
- Definition of Done
- Continuous integration
- Continuous Delivery
- User stories
- Backlog management

Agile methods, continued

- Stand-up meeting
- Spike solutions
- Planning game
- No Overtime
- Collect code ownership
- Travel Light
- System metaphor

Note: when backed into a corner, Agilists will insist that the method or practice is *not the point,* it's the view, or how it's done

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Maintenance and reuse

Re-engineering

Reverse engineering

Program comprehension

Maintenance planning

IT change management

Reuse

- Designing for reuse
- Designing with reuse

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Infrastructure

Basics of ITIL

DevOps

Monitoring

Build Management

Automated deployment

Test data management

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Basics

Big-O notation
Algorithm design
OO languages
Software security basics
Scientific computing
Parallel computing
Numerical methods
Data structures
Functional languages
Encryption basics
Database systems
Game theory

Robotic basics
Aspect-oriented programming
Declarative languages
Network protocols
Distributed computing
State machines
Distributed computing
Procedural languages
Web app security
Machine learning
Artificial intelligence
SW development process

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Implementation & code analysis

Basic coding skills

Code refactoring

Code peer reviews

Code comments

Code format standards

Code reuse

Static code analysis

Dynamic code analysis

Volume metrics

Complexity metrics

Code coverage

Dependency analysis

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Testing

Unit testing

Defect root cause analysis

Integration testing

Service testing

Performance testing

Stress testing

Exploratory testing

Etc.

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Usability

User interface design

User acceptance

Usability labs

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Tools

Code analysis tools

Continuous integration tools

Requirements management tools

Integrated development environment tools

Test automation tools

Profiling tools

Modeling tools

Version control systems

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Management

Risk analysis

Expectation management

Task management

Project management basics

Estimations

Measurement of activities

Project Controlling

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Soft skills

Presentation skills

Training skills

Empathy

Creation of relationships

Conflict management

Negotiation skills

Rhetoric

Intercultural skills

Creativity techniques

Marketing basics

Leadership basics

Good manners

Intrinsic motivation

Physical fitness

Stop talking

Source: http://www.sw-engineering-candies.com/blog-1/periodic-table-of-software-engineering-know-how

Additional information

Interfaces

Conventions and templates

Layering

Algorithmic complexity

Hashing

Caching

Concurrency

Cloud computing

Security (again)

Relational databases

Source: : http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Interfaces

Most important concept in software

Any good software is a model of a real or imagined system

Modeling requires identification of parts and interfaces among them.

Good modeling has correct and simple interfaces

Book on interfaces: Agile programming by Dr. Robert Martin

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Conventions and templates

Naming conventions: indicating function or relationship of a piece of software in its name

Templates help build components

- Template files contain variables
- Allow binding of objects, resolution, and rendering the result for the client

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Layering

Layering*

- Subroutines that only call libraries or system are first layer
- Second layer calls first level or libraries or system
- Etc
- Main() sits at top level

Complexity of a component: How many other components does it rely on?

A good software system is pyramid shaped

- Fewer more-complex components, more less-complex

Precursor to refactoring (continuously sculpting software to ensure it is structurally sound and flexible)

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

* John Lakos: *Large scale C++ software design* (1997)

Algorithmic complexity

Big O notation: Order of size O(n) means linear with the size of data (n) O(n^2) is quadratic with size of data.

Search through a list is O(n), binary search (through a sorted list is log(n). Sorting of n items takes n*log(n) time

Code should not have multiple nested loops. Instead use hash tables, single lists, and singly nested loops

Elegant algorithms improve performance, but we downplay the importance nowadays due to excellent libraries

Having clean and simple algorithms requires compact and readable code

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Hashing

To have fast access to data

Reduces time to find an item as tables get larger by spreading data evenly throughout a table

Uniform hash evenly allocates computers in a cloud database

Google indexes each URL to a particular computer

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Caching

In-memory store of a subset of information typically stored in a database

Example: books that were popular last week: generate once and place into cache. Costly calculations done once

Cost: need to prune, usually by least-recently-used

Modern web applications often used a distributed caching system called Memcached

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Concurrency

Parallelism, inside an application

In Java, threads run concurrently

- Producer/consumer: producer generates data or tasks; queue up for worker threads to consume and execute
- But: threads work on common data
- Core Java contains concurrency libraries

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, augmented by personal knowledge and knowledge from elsewhere

Cloud computing

Grew out of parallel computing: running computations in parallel

Then grid computing (runs parallel computations on idle desktops)

Then application server virtualization

Today: host calculations and databases remotely, including indexing

Enables large-scale computing

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, augmented by personal knowledge and knowledge from elsewhere

Security (again)

Information authentication, authorization, information transmission (among others)

Authorization:

- Verify user identity (password) and keep it secure e.g. by transmitting encrypted (SSL=secure socket layer)
- Define permissions

Network protection

- Identify vulnerabilities
- Configure and monitor to thwart hackers
- Continuous patches as new threats/vulnerabilities are defined

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, as augmented by personal knowledge and knowledge from elsewhere

Relational databases

Fundamental achievement in computing

Good for:

- Order management systems
- Corporate databases
- Profit and loss data

Represents each piece of information, added to a table that defines the type of information

Search using query language such as SQL

Data normalization technique partitions data among tables to reduce data redundancy and maximize retrieval speed

Does not scale well to massive web services

Source: http://readwrite.com/2008/07/ 22/top _10_concepts_that_every_software_engineer_should_know, augmented by personal knowledge and knowledge from elsewhere

Software heuristics from Sprunck

- 'Finding and fixing a software problem after delivery is often 100 times more expensive than finding and fixing it during the requirements and design phase.' [Boehm01]
- 'Current software projects spend about 40 to 50 percent of their effort on avoidable rework.' [Boehm01]
- 'About 80 percent of avoidable rework comes from 20 percent of the defects.' [Boehm01]
- 'About 40 to 50 percent of user programs contain nontrivial defects.' [Boehm01]
- 'About 90 percent of the downtime comes from, at most, 10 percent of the defects.' [Boehm]
- 'Only 60% of the features in a system are actually used in production.' [Bernstein05, p. 249]
- 'About 80 percent of the defects come from 20 percent of the modules, and about half the modules are defect free.' [Boehm01] (aka Pareto principle)
- 'More than 60% of the errors in a software product are committed during the design and less than 40% during coding.' [Bernstein05, page 47]
- 'Peer reviews catch 60 percent of the defects.' [Boehm01]
- 'Perspective-based reviews catch 35 percent more defects than nondirected reviews.' [Boehm01]
- 'Disciplined personal practices can reduce defect introduction rates by up to 75 percent.' [Boehm01]
- 'Testing efforts consume 50% of development time and 20% of project cost. Regression testing halves the time and cost.' [Bernstein05, page 386]
- 'When lines of comments exceeded lines of code, code is hard to read.' [Bernstein05, page 363]