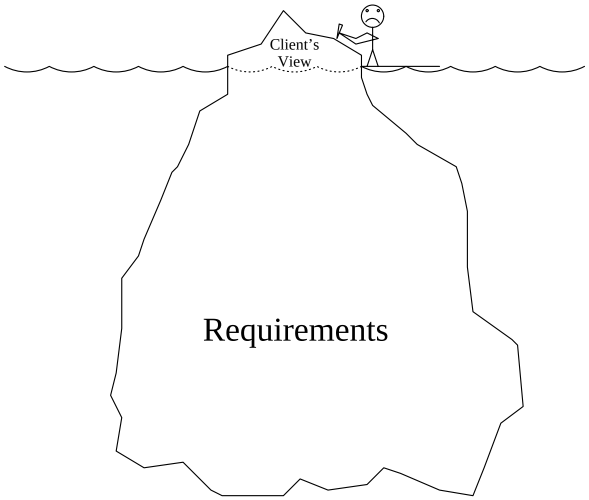
The Requirements Iceberg and Various Icepicks Chipping at it

Daniel M. Berry



Requirements Engineering (RE): the Problems and an Overview of Research

Outline

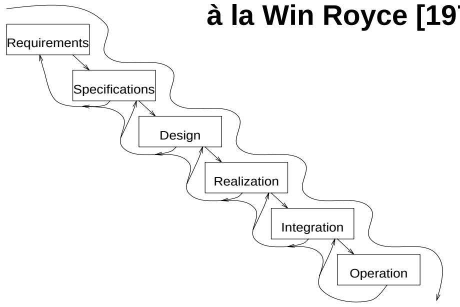
Lifecycle Models
RE is Hard
Why Important to Do RE Early
Myths and Realities
Where Do Requirements Come From?
Formal Methods Needed?
Requirements and Other Engineering
Bottom Line
RE Lifecycle

Outline, Cont'd

- **Overview of Research**
  - **Earlier and Later**
  - **Elicitation**
  - **Analysis**
  - **Natural Language Processing**
  - **Tools**
  - **Changes**
  - **Empirical Studies**
- **Future**

Traditional Waterfall Lifecycle

à la Win Royce [1970]



Only one slight problem: It does not work!

Problems with Waterfall Model

The main problem, from the requirements point of view, of the waterfall model is the feeling it conveys of the sanctity, inviolability, and unchangeability of the requirements, as suggested by the following drawing by Barry Boehm [1988a].

Problems with Waterfall, Cont'd

This view does not work because requirements *always* change:

- **partially from requirements creep (but good project management helps)**
- **partially from mistakes (but prototyping and systematic methods help)**
- **partially because it is inherent in software that is used (the concept of E-type systems is discussed later!)**

Fred Brooks about Waterfall

In ICSE '95 Keynote, Brooks [1995] says "The Waterfall Model is Wrong!"

- **The hardest part of design is deciding *what* to design.**
- **Good design takes upstream jumping at every cascade, sometimes back more than one step.**

Fred Brooks also says:

"There's no silver bullet!" [Brooks 1987]

- **Accidents**
  - **process**
  - **implementation**

  i.e., details

- **Essence**
  - **Requirements**

"No Silver Bullet" (NSB)

- **The *essence* of building software is devising the conceptual construct itself.**
- **This is very hard.**
  - **arbitrary complexity**
  - **conformity to given world**
  - **changes and changeability**
  - **invisibility**

NSB, Cont'd

- **Most productivity gain came from fixing *accidents***
  - **really awkward assembly language**
  - **severe time and space constraints**
  - **long batch turnaround time**
  - **clerical tasks for which tools are helpful**

NSB, Cont'd

- **However, the essence has resisted attack!**

  We have the same sense of being overwhelmed by the immensity of the problem and the seemingly endless details to take care of,

  and we produce the same kind of poorly designed software that makes the same kind of stupid mistakes

  as 35 years ago!

Brooks, Cont'd

Brooks adds, "The hardest single part of building a software system is deciding precisely what to build.... No other part of the work so cripples the resulting system if it is done wrong. No other part is more difficult to rectify later."

Real Life

We see similar requirement problems in real-life situations not at all related to software.

Contracts

We all know how hard it is to get a contract just right ...

to cover all unanticipated situations before they are known.

Houses

We all know how hard it is to get a house plan just right before starting to build the house.

Contractors even *plan* on this; they underbid on the basic plan, expecting to be able to overcharge on the inevitable changes the client thinks of later.

Homework Assignments

We all know how hard it is to get the specification of a programming homework assignment right, especially when the instructor must invent new ones for every run of the course.

IEEE Definition of Requirement

1. **a condition or capability needed by a user to solve a problem or achieve an objective**
2. **a condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document**
3. **a documented representation of a condition or capability as in (1) or (2)**

Kinds of Requirements

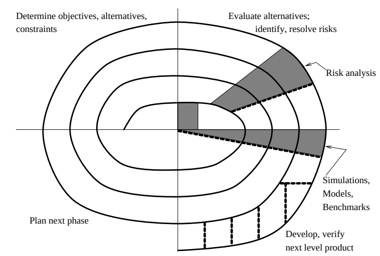
- **functional—what the system should do**
- **non-functional—constraints on system or process, quality requirements**

Some non-functional requirements (NFR) are not specifiable, e.g., user friendliness.

It is often difficult to distinguish the two, e.g., a response time.

More Realistic Spiral Model

à la Barry Boehm [1988b]



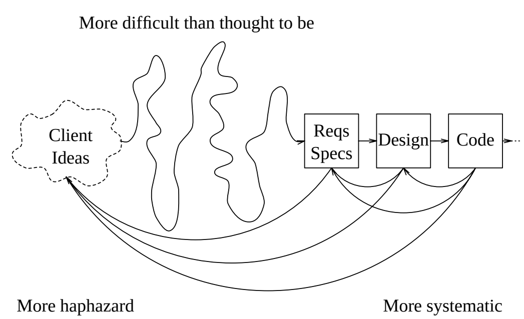
One may even follow the waterfall in each 360° sweep of the spiral.

Spiral Model

That is, the requirements and the implementation are developed incrementally.

That requirements are changing is planned.

REAL Lifecycle for One Sweep



Agreed?

Requirements Engineering

That wavy line between Client Ideas and Requirements Specifications is RE.

Loucopoulos's Definition of RE

Loucopoulos and Karakostas [1995]:

RE is a systematic process of

- **developing requirements through an iterative cooperative process of analyzing the problem,**
- **documenting the resulting observations in a variety of representation formats, and**
- **checking the accuracy of the understanding gained.**

Hsia's Definition of RE

RE is all activities which are related to

- **identifying and documenting customer and user needs,**
- **creating a document that describes the external behavior and associated constraints that will satisfy those needs,**
- **analyzing and validating the requirements document to insure consistency, completeness and feasibility, and**
- **evolution of these needs.**

Zave's Definition of RE

Pamela Zave [1997]:

RE is the branch of SE concerned with real-world goals for, functions of, and constraints on software systems. It is also concerned with the relationship of these factors to precise specifications of software behavior, and to their evolution over time and across software families.

Zave's Definition of RE, Cont'd

Important aspects of definition [Nuseibeh & Easterbrook 2000]:

- **real-world goals**
  - **what**
  - **why**
- **precise specifications, basis for**
  - **analyzing requirements**
  - **validating with stakeholders**
  - **defining what is to be built**
  - **verifying implementation**

Zave's Definition of RE, Cont'd

- **evolution**
  - **over time for a changing world**
  - **across families with partial reuse**

Systems, Not Just Software

Bashar Nuseibeh & Steve Easterbrook [2000]:

RE has been called a branch of Software Engineering.

In reality, software cannot function in isolation from the system in which it is embedded.

Prefer to characterize RE as a branch of Systems Engineering.

Ryan's Definition of RE

RE is the development and use of cost-effective technology for the elicitation, specification and analysis of the stakeholder requirements which are to be met by software intensive systems.

Stakeholders

A stakeholder is a person who is directly or indirectly affected by the system under construction, .e.g.,

- **customers and users**
- **marketing and sales personnel**
- **developers and testers**
- **maintainers**
- **managers**

But ‘X Engineering’ is Illegal

“Engineering” is a controlled term, not legal to use with “Requirements”.

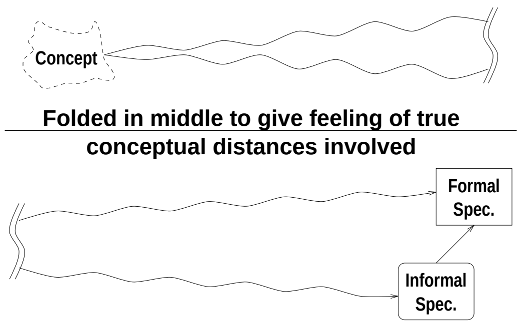
The term “RE” is used as a reminder that the gathering of requirements occurs as part of an *engineering* process.

RE is Hard

How hard?

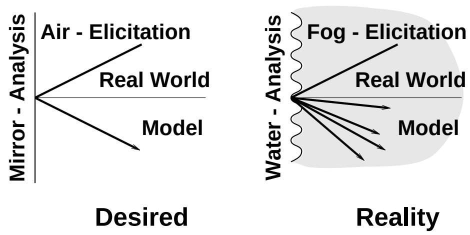
Like fighting a platoon of angry, slightly inebriated Klingons.

Distance: Concept → Specs



Modeling Difficulties

Brian Mathews has another view in terms of modeling



What vs. How

A requirements specification is supposed to describe what the system should do and not how.

It is not easy to obey this rule in practice.

What vs. How, Cont'd

One person's how is another person's what; to an author, a WORD data structure is a how issue, but to a system programmer, a data structure in UNIX is a what issue.

In model of multiple levels of abstraction, each level is both the how of the level above and the what of the level below. [Ryan 1998]

Three Kinds of Requirements

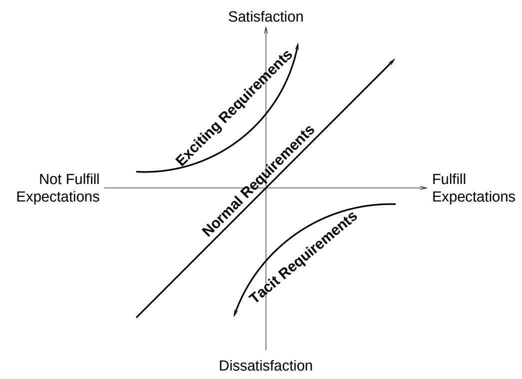
Krogstie [1998] identifies 3 kinds of system requirements.

1. ***Normal*—Users mention these with no problems.**
   They contribute proportionally to user satisfaction of the system.
2. ***Exciting*—Creative developers invent these.**
   They contribute dramatically to user satisfaction of the system.

Three Kinds, Cont'd

3. ***Tacit*—Users understand these, but do not mention them; developers do not see these.**
   Unfound by developers, they contribute dramatically to user dissatisfaction of the system.

Three Kinds, Cont'd



Errors and Requirements

According to Barry Boehm [1981] and others, around 75-85% of all errors found in SW can be traced back to the requirements and design phases.

Errors and Requirements, Cont'd

Those data say that we are doing a pretty good job of implementing of what we *think* we want.

But, we are doing a lousy job of knowing what we want.

Errors and Requirements, Cont'd

Either

- **the erroneous behavior is required because the situation causing the error was not understood or expressed correctly, or**

- **the erroneous behavior happens because the requirements simply do not mention the situation causing the error, and something not planned and not appropriate happens.**

Worth Fixing an Error?

Sometimes it's not worth fixing a requirements error in software that works pretty well. That is, it's not worth modifying the software to meet a newly discovered requirement.

E.g., at U of Waterloo, a system called QUEST has automated course scheduling and registration so that a student can register on line via the WWW.

Worth Fixing an Error, Cont'd?

For each course *C* for which a student *S* tries to register, QUEST checks that *S* has successfully taken all the prerequisites for *C*.

However, there are degree programs, e.g., ConGESE, that use regular courses, but in a non-normal sequence. In this program, because everyone is already a practicing software engineer, no course has any prerequisites.

Worth Fixing an Error? Cont'd

Thus when a ConGESE student tries to register for the RE course I teach at UW, he or she is usually not allowed to register because he or she has not taken any of the prerequisite courses.

This situation was never considered in developing QUEST.

Worth Fixing an Error? Cont'd

Fortunately, QUEST has provided for superusers that can force QUEST to accept registrations that would otherwise not be allowed. So the students were able to be registered.

Worth Fixing an Error? Cont'd

Is it worth changing QUEST?

Decidely, "No!".

The frequency of the ConGESE situation is once every two years and the number of students involved is between 10 and 20 each time.

It's easy enough for a superuser to handle the situation manually.

Worth Fixing an Error? Cont'd

Modifying the software risks introducing bugs.

This change would be rather complex because it would have to introduce a notion of independent streams with different prerequisite structures and force prerequisites to be associated not with just a course, but a course and a program together. Implementing this means changing the whole course abstraction. Yecch!

Worth Fixing an Error? Cont'd

So this bug is declared as a feature, and the superuser intervention becomes the official way to deal with ConGESE course registrations.

The same solution will be applied to any other degree program with similar requirements....

Until such time as there are so many other programs that superuser intervention becomes burdensome.

Paradox

Fred Brooks observed that a general purpose system is harder to design than a special purpose product.

Study of Requirement Errors

by Martin & Tsai [1988]

Experiment to identify lifecycle stages in which requirement errors are found

Polished 10-page requirements for centralized railroad traffic controller

Ten 4-person teams of software engineers

User believed that teams would find only 1 or 2 errors

Study, Cont’d

92 errors, some very serious, were found!

Average team found only 35.5 errors, i.e., it missed 56.5 to be found downstream!

Many errors found by *only* one team!

Errors of greatest severity found by fewest teams!

Michael Jackson Says

In a Requirements Engineering ’94 Keynote, Jackson [1994] says:

Two things are known about requirements:

1. They will change!

2. They will be misunderstood!

Tacit Assumption Tarpit

Tacit Assumptions, Cont'd

Those tacit assumptions of the problem are reasonable, right?

Well, the source of most disasters, such as at nuclear power plants, is perfectly reasonable, possibly explicit but usually tacit, assumptions that did not hold in some special circumstances that nobody thought about.

Timely Tacit Assumptions

According to the UW schedule, a TA had a laboratory scheduled for "8:00" (with no "am" or "pm"). He and some students assumed that it was at 8:00am. Most students assumed that it was at 8:00pm. The university meant "8:00pm".

Perhaps, those who assumed it was "8:00am" could have figured that since classes start at 8:30am, "8:00" had to be "8:00pm", but that's stretching it.

Timely Tacit Assumptions, Cont'd

The university schedule should have made it clear that it was at 8:00pm.

The reason it did not say "8:00pm" is that there is no "pm" designation because in most cases, from from 12:00 until 5:00, it is obvious that "pm" is meant. Who goes to class at 4:00am?

More Timely Tacit Assumptions

Once in Tel Aviv, I read a Hebrew no-parking sign saying "8:00–17:00" as saying that there is no parking from 5:00pm until 8:00am the next morning to reserve parking places for the people who live on the street, who would have special exemption certificates.

According to the city of Tel Aviv, the sign means that there is no parking from 8:00am until 5:00pm to keep the street traversable during the business day.

Timely Tacit Assumptions, Cont'd

According to Hebrew reading rules, I am correct and the city is wrong.

While numerals are read from left to right, the flow of the sentence is from right to left and the "–" is *not* part of each numeral.

I could not get the city to see their error and cancel the ticket!

Requirements Always Change

In a Requirements Engineering '94 Keynote, Michael Jackson says:

Two things are known about requirements:

1. ***They will change!***
2. **They will be misunderstood!**

Why will they *always* change?

E-Type Software

à la Meir Lehman [Lehman 1980]

A system that solves a problem or implements an application in some *real world* domain.

Once installed, an E-type system becomes inextricably part of the application domain, so that it ends up altering its own requirements.

E-Type Software, Cont'd

Example:

- **Consider a bank that exercises an *option* to automate its process and then discovers that it can handle more customers.**
- **It promotes and gets new customers, easily handled by the new system but beyond the capacity of the manual way.**
- **It cannot back out of automation.**
- **The requirements of the system have changed!**

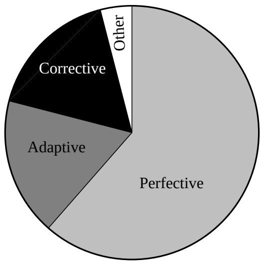
E-Type Software, Cont'd

Daily use of a system causes an irresistible ambition to improve it as users begin to suggest improvements.

Who is not familiar with that, from either end?

E-Type Software, Cont'd

In fact, data show that most maintenance is *not* corrective, but for dealing with E-type pressures!



RE is Hard

Despite the clear benefits of getting requirements complete, right, and error-free early, they are the hardest part of the system development lifecycle to do right because:

- **we don't always understand everything about the real world that we need to know,**

- **we may understand a lot, but we cannot express everything that we know,**

RE is Hard, Cont'd

- we may think we understand a lot, but our understanding may be wrong,
- requirements change as client's needs change,

RE is Hard, Cont'd

- requirements change as clients and users think of new things they want, and
- requirements of a system change as a direct result of deploying the system, as pointed out by Meir Lehman.

Sources of RE Difficulties

- RE is where informal meets formal (says Michael Jackson [1995]).
- Many requirements are created, not found.
- Users, buyers, even developers may be unknown.
- Stakeholders have conflicting objectives.
- Multiple views exist.
- Inconsistency must be tolerated, for a while.
- Requirements evolve during and after development.

The TRUTH About Methodology Literature

Did you ever notice how error- and backtracking-free are example developments from clean requirements in the methodology literature?

Have you ever noticed how your own developments never go quite as smoothly and how your requirements are never totally right?

Truth, Cont’d

As an author of some of this literature, I will let you in on a little secret!

Shhh!

What you see in the literature is cleaned up from the rather messy real-life development.

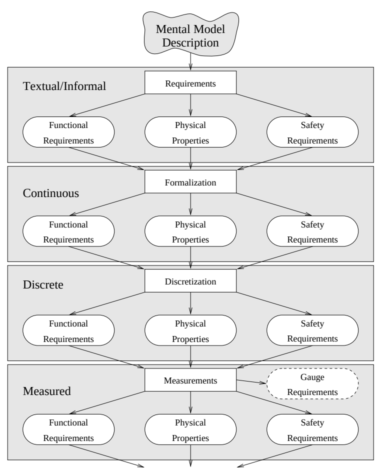
The requirements specification was modified more than the design and code.

Nu?

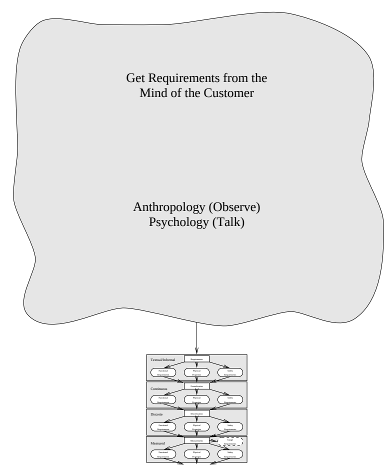
Montenegro’s View

Sergio Montenegro described the reality by showing an older view of the requirements engineering process:

and then a newer view, formed after hearing an earlier version of this talk:



Subprocesses of the Requirements Phase



Relation between Getting and Formalizing Requirements

Why Important to Do RE Early

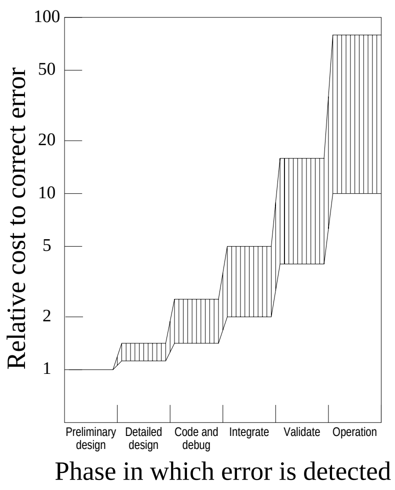
The BIG Question:

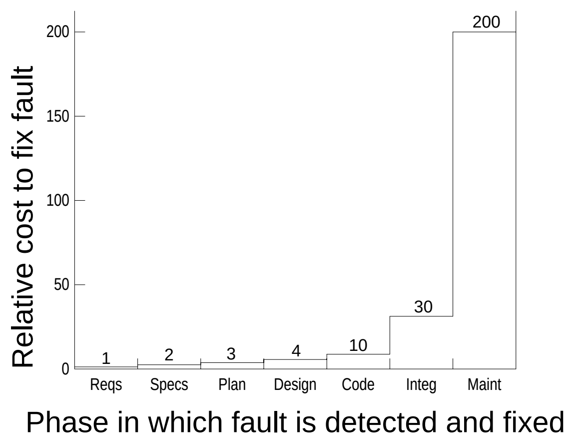
Why is it so important to get the requirements right early in the lifecycle? [Boehm 1981, Schach 1992]

We know that it is much cheaper to fix an error at requirements time than any time later in the lifecycle.

Cost to Fix Errors

Barry Boehm's (next slide) and Steve Schach's (slide after that) summaries of data over many application areas show that fixing an error after delivery costs two orders of magnitude more than fixing it it at RE time.





Conclusion...

Therefore, it pays to find errors during RE.

Reliability, Safety, Security, & Survivability

We know that we cannot program reliability, safety, security, and survivability into the code of a system only at implementation time. They must be required from the beginning so that consideration of their properties permeate the entire system development.

The wrong requirements can preclude coding them at implementation time.

User Interfaces (& Errors)

The same is true about good user interfaces.

They cannot be programmed in later.

They must be required in from the beginning [Shneiderman 1984, Kösters, Six & Voss 1996].

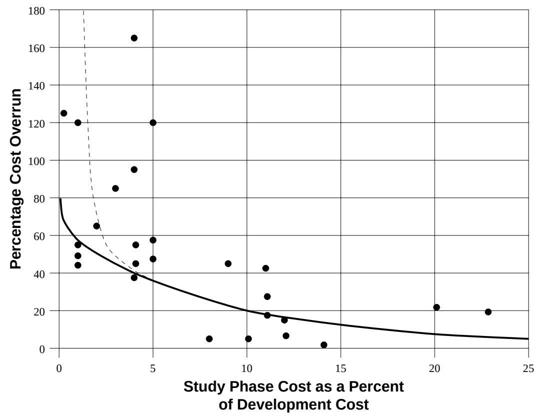
Same is true also about system responses to erroneous input.

RE & Project Costs

The next slide shows the benefits of spending a significant percentage of development costs on studying the requirements.

It is a graph by Kevin Forsberg and Harold Mooz relating percentage cost overrun to study phase cost as a percentage of development cost in 25 NASA projects.

Project Costs, Cont’d



Project Costs, Cont’d

The study, performed by W. Gruhl at NASA HQ includes such projects as

- Hubble Space Telescope
- TDRSS
- Gamma Ray Obs 1978
- Gamma Ray Obs 1982
- SeaSat
- Pioneer Venus
- Voyager

Some Advantages of Project Delay

Arnis Daugulis [1998] reports a significant increase in the quality of the requirements for a power plant control system as a result of delays in start of production caused by shortage of funds.

They had the luxury of time to do two revisions of the requirements.

He shudders to think of the failure that would have resulted had they started to implement the first requirements on time.

Myths and Realities

A bunch of myths about requirements and the answering realities

Coding before RE

Several related myths:

> ***"You people start the coding while I go find out what the customer wants."***
>
> ***Requirements are easy to obtain.***
>
> ***The client/user knows what he/she wants.***

Coding before RE, Cont'd

According to Ruth Ravenel, ...

> **The programmer who says the first line is suffering from the myth that the customer would be able to know what he or she wants and to say it just because the programmer asked.**

Need Prototype

> **Most people (especially non-technically oriented) learn while doing; they've got to see some kind of prototype (even if it's only yellow stickies on a board) to *discover* what they want.**

First also expresses the nonsensical notion that somehow, coding can begin before it's known *what* to code.

IKIWISI

I'll know it when I see it!

This is how most clients really identify requirements.

They cannot tell you what they want, but if they see what they want, they spot it immediately!

We Don’t Have Time for RE

“*I know that it is important to get requirements, but we don’t have time for it; we have to get to coding to meet our deadline!*”

We Don’t Have Time, Cont’d

At least one Ph.B. has been heard to say, “Wally, we don’t have time to gather the product requirements ahead of time. I want you to start designing the product anyway. Otherwise it will look like we aren’t accomplishing anything.”

Wally stops working because he knows that the project is doomed anyway.

We Don’t Have Time, Cont’d

I will prove that we, in fact, always do write requirements during the normal commercial software lifecycle.

Therefore, we always have time.

Never Needed RE Before

“We’ve* never *written a requirements document and we’re still successful!”

So says the manager of a project that delivered tested software with a user’s manual or an on-line help.

So says the manager justifying a decision to plunge into development without first determining and specifying requirements.

Sorry to Disappoint You!

Kamsties, Hörmann, and Schlich [1998] observe:

Any project that does testing has to determine the requirements in order to determine covering test cases and their expected outputs. The test plan ends up being a requirements specification.

Sorry, Cont'd

Any project that produces user documentation has to determine the requirements in order that the documentation describe all of the features well. The documentation ends up being a requirements specification.

So there is no escaping determination and specification of requirements (unless you don't do testing and user documentation!).

Sorry, Cont'd

There is no avoiding the time required to determine and specify the requirements.

However, if you produce requirements only as a side effect of testing and documentation, you lose the key benefit of *early* requirements determination and specification, namely finding errors at the least cost.

May Not Even Have a Problem!

The client often says that he or she requires a specific solution of an unknown or nonexistent problem rather than any solution to a specific problem.

"*We gotta automate!*"

The problem with such a client is that there may not even be a problem that requires any solution, or if there is, other solutions, including non-computer, may be better!

Another Myth

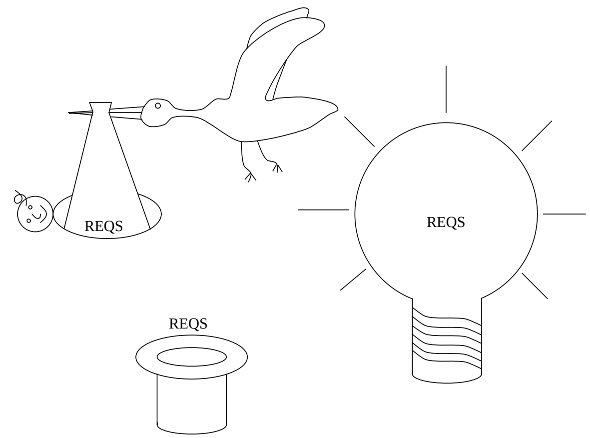
After the requirements are frozen, ...

Ha!
Ha ha!
Ha ha ha!
Ha ha ha ha!

The only clients that are satisfied and have stopped asking for changes are themselves frozen!

We have already seen why requirements will *never* be frozen!

Whence Do Requirements Come?



Whence, Cont'd

Joe Goguen [1994a] says, "It is not quite accurate to say that requirements are in the minds of clients; it would be more accurate to say that they are in the social system of the client organization. They have to be invented, not captured or elicited, and that invention has to be a cooperative venture involving the client, the users, and the developers. The difficulties are mainly social, political, and cultural, and not technical."

Whence, Cont'd

Interviewing does not really help because when asked what they do, most people will quote the official policy, and not what they actually do. Most of what they really do, which is not specified by the policy, is what they do in situations not covered by the policy.

We're not even talking about conscious, politically safe mouthing of the policy.

Whence, Cont'd

Many people simply do not remember the exceptions unless and until they actually come up. Their conscious model of what happens *is* the policy.

Therefore, the requirements engineer has to *be* there when the exceptional situations come up in order to *see* what really happens.

Whence, Cont'd

Moreover, many people just do not know *why* they do something, saying only that it's done this way because the policy says so.

They very often do not even know why the policy is the way it is.

Whence, Cont'd

Moreover, many people just do not know *how* they do something, drawing a complete blank or saying only, "Watch me!".

For example, how do *you* ride a bicycle? Nu?

Whence, Cont'd

Don Gause and Jerry Weinberg [1989] tell the story of the woman who always cuts off ⅓ of a raw roast before cooking both pieces together.

She was asked "Why?" ... "???"

Her mother was asked "Why?" ... "???"

Her grandmother was asked "Why?" ...

Whence, Cont'd

Because the pot of this woman's grandmother was too small to accommodate the full length piece. Nu?

Whence, Cont'd

In other words, the policy once made sense, but the person who formulated the policy, the reasons for it, and the understanding of the reasons are long since gone.

Whence, Cont'd

For example, many companies that have committed all data to a highly reliable data base continue to print out the summary in quintuplicate.

Why? At the time of automation, the five most senior members of the company, who long ago retired, refused to learn to use the computer to access the data directly!

Creativity

Roberto Tom Price reminds us not to forget the requirement engineer's

- **imagination**
- **ideas**
- **suggestions**

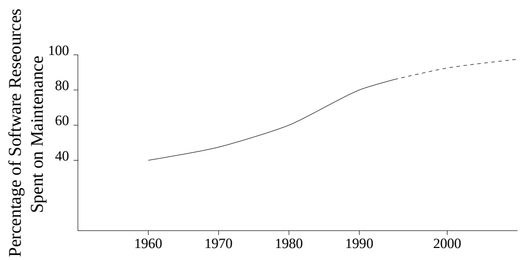
like an architect for a new building, following input from the client

Whence, Cont'd

Goguen further observes that most of the effort for a typical large system goes into maintenance.

In fact, Parnas [1994] has the data:

Whence, Cont'd

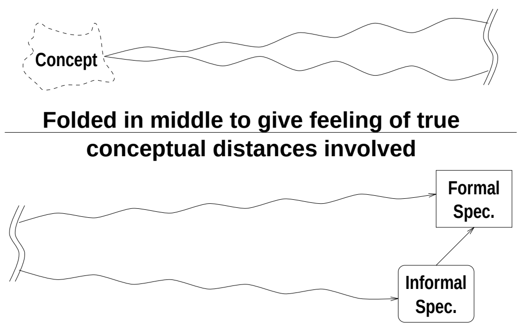


Growing Percentage of Maintenance Costs

Formal Methods Needed?

Some formal methodologists say that this is the fault of insufficient effort put into being precise in the early, specification stages of software development.

However, recall the conceptual distances involved:



FMs Needed, Cont'd

Goguen believes that "a deeper reason is that much more is going on during so-called maintenance than is generally realized. In particular, reassessment and re-doing of requirements, specification, and code, as well as documentation and validation, are very much part of maintenance...."

FMs Needed, Cont'd

Later, he adds, "it only becomes clear what the requirements really are when the system is successfully operating in its social and organisational context.... it is impossible to completely formalise requirements ... because they cannot be fully separated from their social context."

This is precisely the phenomenon of E-type systems.

Formal Methods Myths

Goguen has identified other myths about requirements, again based on the mistaken idea that the hard part about requirements are their specification.

FM Myths, Cont'd

If* only *you had written a formal specification of the system, you wouldn't be having these problems.

Mathematical precision in the derivation of software eliminates imprecision.

FM Myths, Cont'd

What is the reality?

Yes, formal specification are extremely useful in identifying inconsistencies in requirements specifications, especially if one carries out some minimal proofs of consistency and constraint or invariant preservation, ...

just as writing a program for the specification!

FM Myths, Cont'd

Don't get me wrong.

This formality is good, because it finds errors early, thus reducing the costs to fix them.

However, formal methods do *not* find all gaps in understanding!

FM Myths, Cont'd

As Eugene Strand and Warren Jones [1982] observe, "Omissions of function are often difficult for the user to recognize in formal specifications"....

just as they are in programs!

FM Myths, Cont'd

von Neumann and Morgenstern (*Theory of Games*) say,

"There's no point to using exact methods where there's no clarity in the concepts and issues to which they are to be applied."

Preservation of Difficulty

Indeed, Oded Sudarsky has pointed out the phenomenon of *preservation of difficulty*. Specifically, difficulties caused by lack of understanding of the real world situation are not eliminated by use of formal methods; instead the misunderstanding gets formalized into the specifications, and may even be harder to recognize simply because formal definitions are harder to read by the clients.

Bubbles in Wall Paper

Sudarsky adds that formal specification methods just shift the difficulty from the implementation phase to the specification phase. The "air-bubble-under-wallpaper" metaphor applies here; you press on the bubble in one place, and it pops up somewhere else.

One Saving Grace

Lest, you think I am totally against formal methods, they *do* have one positive effect, and it's a BIG one:

Use of them increases the correctness of the specifications.

Therefore you find more bugs at specification time than without them, saving considerable money for each bug found earlier rather than later.

Analogy with Math Theory

Building new software is like building a new mathematical theory from the ground up:

- **Requirements gathering: deciding what is to be assumed, defined, and proved**
- **Development as a whole: assuming assumptions, defining the terms, and proving the theorems**

Math Theory, Cont'd

- **Design: determining the sequence of assumptions, definitions, and theorems to build the theory**
- **Implementation: carrying out the designed theory and proving the theorems**

Math Theory, Cont'd

Mathematical papers and books show only the results of the implementation,

This implementation is what is considered the mathematics, and not the requirements gathering and design that went into it.

But I know, from my own secret past life as a mathematician, that the hard, time consuming parts are the requirements gathering and design.

Math vs. SW Development

- **Software is usually developed under strict time constraints, and mathematics is usually not.**
- **Mathematics development is subjected to error-eliminating social processes, and software development is subjected to a lot less.**

Math vs. SW, Cont'd

- **Mathematics is written for a human audience that is very forgiving of minor errors so long as it can see the main point; software is written for the computer that is very literal and unforgiving of minor errors**

  - **For people, UKWIM works, and they accept imprecision.**
  - **For computers, UKWIM and DWIM do not work, and they do not accept imprecision.**

Another Implication of Growing Maintenance Costs

For many programs, which are more and more often enhancements of legacy software, any original requirements specifications that may have existed are long gone.

The original programmers are long gone.

The old requirements have to be inferred from the software.

Another Implication, Cont'd

What is inferred may not capture all features.

Also the obvious requirement of not impacting existing functions in the enhancement is very easy to state, but, oh, so hard to satisfy.

RE and Other Engineering

Speaking of architects and other engineers that get requirements from clients, ...

While software requirements gathering has much in common with requirements gathering for buildings, bridges, cars, etc., there are significant differences in:

- **the flexibility and malleability of the medium, and**
- **the degree to which basic assumptions are on the table, up for grabs.**

Other Engineering, Cont'd

Michael Jackson [1998] considers the more traditional engineering disciplines.

Civil Engineering
Mechanical Engineering
Aeronautical Engineering
Electrical Engineering

Their engineers make machines by describing them and *then* building them.

Other Engineering, Cont'd

Software engineers make machines merely by describing them.

Software is an intangible, infinitely malleable medium.

Other Engineering, Cont'd

To build a new car from requirements the way software is built from requirements would be called *totally rethinking the automobile*. In fact, each new kind of car is really a minor perturbation of existing kinds of cars.

Other Engineering, Cont'd

Perhaps, we should do much more minor perturbation of existing software, i.e., practice reuse, but in many cases we cannot, simply because we are developing software for an entirely new application.

Bottom Line

The notions that

- **one can derive requirements or**
- **even interview a few people to get requirements**

are patent nonsense.

Ample Evidence That

- **The later an error is detected, the more it costs to correct it.**
- **Many errors are made in requirements elicitation and definition.**
- **Many requirements errors can be detected early in the lifecycle.**
- **Typical errors include incorrect facts, omissions, inconsistencies, and ambiguities.**
- **Requirements problems are industry's biggest concern.**

OK, OK, You're Convinced!!!

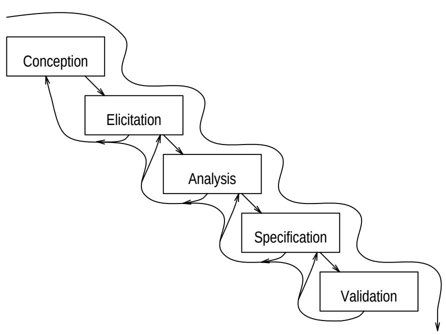
So what do we DO about it?

What research is being done to solve the problems?

First, recognize that the problem is HARD!

Second, recognize that requirements engineering has its own lifecycle

Requirements Engineering Lifecycle



RE Lifecycle, Cont'd

This, of course, is an idealization, just as much as the original waterfall.

Reality is that there is a spiral, with each sweep going through this entire subwaterfall, and all the steps in the sweep happening concurrently.

Another RE Lifecycle

Kevin Ryan offers the following RE process:

- **Identify Requirements**
- **Document Requirements**
- **Validate Requirements—Have we elicited and documented the right requirements?**
- **Verify—Have we got the model right— and Validate—Have got the right model—Models**
- **Rank Requirements by Priority**
- **Select and Plan Requirements**

Scoping

Some facts:

- **Many projects fail because what was required was too big for the available resources, and there is no way to subset the requirements, i.e., it's all or nothing!**
- **80% of execution is in 20% of the code, a rule of thumb used by compiler writers.**

Scoping, Cont'd

- **1998 Standish Group data [Neumann 1999] show that among features in sampled mass-marketed applications,**
  - **45% are never used,**
  - **19% are rarely used,**
  - **16% are sometimes used,**
  - **13% are often used, and only**
  - **7% are always used.**

Must Scope Requirements

The solution to these problems is to scope, but how?

Must rank requirements

1. **absolutely essential**
2. **essential**
3. **important**
4. **nice**
5. **fluff**

Subsetting Requirements

Select an affordable, coherent subset of the requirements consisting of the most important requirements.

OR

Build to cost, perhaps in a spiral.

It's Still an Art

And most importantly, ...

There are no real solutions yet!

It is very much an art form.

Research Topics

Earlier Work, prior to mid-80s

Later Work, mostly after mid-80s

Some temporal overlap, because as we will see, the work is classified by nature, and that nature has changed slowly.

I apologize in advance if I have left out things about which I am not aware.

Earlier Work-1

Languages and Tools:

PSL/PSA [Teichroew 1977]
SADT [Ross and Ross & Schoman 1977]
RSL [Alford 1977]
RDL [Winchester 1982]
PAISley [Zave 1982]
RML [Borgida, Greenspan & Mylopoulos 1985]
IORL [Salton & McGill 1983]

Earlier Work-2

Alan Davis wrote the book! *Requirements Analysis and Specification* [1990]

Focus was on analysis and specification, *not* on elicitation

Later Work-1

More consideration of elicitation

Recognition of importance of sociology and psychology

Later Work-2

- **Elicitation**
- **Analysis**
- **Natural Language Processing**
- **Tools and Environments**
- **Changes**
- **Empirical Studies**
- **RE as a Human Activity**

Global View-1

***Requirements Engineering* is:**

How to squeeze requirements out of the client’s mind and environment without damaging the client or the environment!

***Elicitation* is:**

How to squeeze information out of the client’s mind without damaging the client!

Global View-2

Analysis **is:**

How to squeeze as much additional information as possible out of what has been obtained by squeezing the client and the environment!

Natural Language Processing **(NLP) is concerned with:**

How to automate as much of the analysis squeezing as possible

Global View-3

Tools and Environments **deal with:**

How to automate the storage of information before and after analytic squeezing as well as all kinds of squeezing!

Changes **cause that:**

No matter how hard you squeeze, analyze, etc. there are new requirements, and the old ones change.

Global View-4

Empirical Studies **are concerned with:**

Understanding squeezing by observing it or parts of it in real-life circumstances!

RE as a Human Activity **is concerned with:**

Understanding how humans do the squeezing as a social activity.

Use of Exemplars in RE Research

Many areas of SE use published exemplars, e.g., the KWIC Index System, for research case studies.

Since the problem is *how* to get the information for requirements, published exemplars are too polished and too late.

What is normally done to prepare exemplars for publication *is* the subject

Post Mortem Reports

Post mortem reports from failed projects, e.g., the automation of the London Ambulance Service [Finkelstein & Dowell 96] dispatching system, provide useful insight in how *not* to do requirements engineering.

Interestingly, the LAS learned its own lessons and won the 1997 British Computer Society Excellence Award!

Elicitation Overview-1

The gist of the specific work is:

- **Identify the stakeholders; these are the people you have to ask!**
- **The customer is always right.**
- **People matter.**
- **Interviewing does not get all the information that is needed.**

Elicitation Overview-2

- **The requirements engineer should get into the client's work place, blend into the woodwork or among the employees, and observe, learn, and question, in order to overcome ignorance of the problem domain.**
- **The requirements engineer should become an employee of the client to learn the ropes well enough to understand the underlying rationale behind the way things are done.**

Elicitation Overview-3

- **The requirements engineer should parlay his or her ignorance into on-the-spot questions that expose tacit assumptions and special cases.**
- **Don't tell them what you mean; show them! This works in both directions!**
- **Prototype to capture emergent requirements and contextual factors.**

Elicitation Overview-4

- Getting all stakeholders together for week-long facilitated meetings at which the requirements are shlogged out together buys commitment from all stakeholders.
- Scenarios and use-cases, which are descriptions of the ways that the intended system will be used to achieve specific or classes of tasks, are a useful way to focus users' attention on what they actually do and to document what they really do in the course of doing their work.

Elicitation Specifics-1

- Ignorance hiding in elicitation and analysis [Berry 1980, 1983]
- Scenarios and Use Cases [Hooper & Hsia 1982, Jacobson 1992]
- Concept of abstract user and prototype elicitation management tool [Burstin 1984]
- Brainstorming [Gause & Weinberg 1989]
- Contextual Inquiry, an anthropological approach to understanding client [Holtzblatt & Jones 1990, Beyer & Holtzblatt 1998]

Elicitation Specifics-2

- Study of discourses in elicitation techniques, e.g., interviews [Goguen & Linde 1993]
- Storyboarding & paper mockups [Zahniser 1993]
- Joint Application Development [Carmel, Whitaker & George 1993] [Wood & Silver 1995]
- Importance of ignorance in elicitation [Berry 1995]

Elicitation Specifics-3

- Stakeholder Identification [Sharp, Finkelstein & Galal 1999]
- Scenarios and Prototyping to capture emergent contextual factors [Carroll, Rosson, Chin, & Koenemann 1998, Dzida & Freitag 1998]

Analysis Overview-1

- Basic idea of analysis is to
  - derive implications of,
  - resolve inconsistencies in, and
  - determine what is missing from

  the information that has been gathered so far so that follow up questions may be asked.
- A key job of the analyst is to model the system under design and its environment. This is hard work, but from a good model, requirements are almost there for picking.

Analysis Overview-2

- Modeling the enterprise in which the requirements are situated is essential.
- The requirements engineer must constantly attempt to validate his or her understanding with the client or user.
- Prototypes are a nice way to make models and scenarios concrete to clients and users.
- Clients' and Users' validation responses to prototypes are far more credible than to long written specifications.

Analysis Overview-3

- One has to be careful about the information content of a prototype, what is there and not, what is intended and not, in short, its meaning.
- It is essential to be able to trace the history of a requirement from its conception through its specification and on to its implementation.
- Tracing allows determining the meaning of a prototype.

Analysis Overview-4

- Distilling scenarios into use cases is a useful way to put some order into the myriad scenarios described by diverse users.
- Error checking, handling, and prevention will not happen in a program *unless* they are explicitly required of the program; this is particularly so in safety-critical software for which the dangers are not readily apparent.

Analysis Overview-5

- **While being specified, requirements *are* logically inconsistent.**
- **Goals and intents are important to understand and document.**
- **Ranking requirements by priority allows scoping, which in turn allows building to resources.**
- **Requirements and design affect each other.**

Analysis Overview-6

- **Dealing with non-functional requirements (NFR) is tough since often they are not quantifiable or expressible.**
- **Analysis = Modeling, Modeling, Modeling!**
  - **Enterprise Modeling**
  - **Data Modeling**
  - **Behavioral Modeling**
  - **Domain Modeling**
  - **NFR Modeling**

Analysis Specifics-1

- **Prototyping for requirements discovery and validation [Wasserman et al 1984 & 1986, Bowers & Pycock 1993, Luqi 1992]**
- **Software safety fault isolation techniques [Leveson 1986 & 1995]**
- **Viewpoint Resolution [Leite 1987, Easterbrook 1993]**
- **Brainstorming [Gause & Weinberg 1989]**
- **Issue-based information system (IBIS) [Burgess-Yakemovic & Conklin 1990]**

Analysis Specifics-2

- **Domain modeling [many, surveys: Kang *et al* 1990, Lubars *et al* 1993]**
- **Object-orientation as a natural view [many, including: Coad & Yourdon 1991, Zucconi 1993]**
- **Non-Functional Requirements [Mylopoulos, Chung & Nixon 1992].**
- **Enterprise Modeling with Scenarios [Mylopoulos, Chung & Nixon 1992].**
- **Goal-directed RE [Dardenne, van Lamsweerde & Fickas 1993]**

Analysis Specifics-3

- **System Scoping & Bounding [Drake & Tsai 1994]**
- **Requirements Traceability [Gotel & Finkelstein 1994]**
- **Living with Logical Inconsistency of Specs [Easterbrook & Nuseibeh 1995, 1996, Hunter & Nuseibeh 1997]**
- **Ranking Requirements by Priority [Karlsson & Ryan 1997]**
- **Intent Specifications [Leveson 1997]**

NLP Overview-1

The total amount of information to deal with for any real problem is HUGE and repetitititive.

We desire assistance in extracting useful information from this mass of information.

NLP Overview-2

We would like the extracted information to be

- **summarizing,**
- **meaningful, and**
- **covering.**

From 500 pages, we want 5 pages containing *all* and *only* the meaningful information in the 500 pages.

NLP Overview-3

We prefer less summarization and occasional meaningless stuff than to lose some meaningful stuff, because in any case, a human will have to read the output and at that time can filter out the meaningless stuff.

Stupidity is preferred to intelligence if the latter can lose information as a result of it not ever being perfect.

NLP Overview-4

Expressing scenarios in natural language keeps them understandable by the clients and users but runs the risk of ambiguity.

The user's manual, written in natural language, turns out to be a very good requirements specification.

NLP Specifics-1

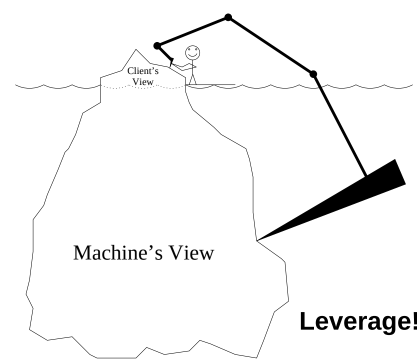
- **Restricted natural language processing of requirements ideas to get specifications [Saeki, Horai, *et al* 1987]**
- **Natural language abstraction identification with lexical affinities [Maarek 1989]**
- **Application domain lexicon building and tools [Leite & Franco 1993]**

NLP Specifics-2

- **AI-based natural language processing [Ryan 1993]**
- **Nonintelligent, fully covering natural language abstraction identification using signal processing techniques [Goldin 1994]**
- **Scenarios in Natural Languages [Somé, Dssouli, & Vaucher 1996]**

Martin Feather's View of RE Tools

The Requirements Iceberg and Various Machine-Assisted Icepicks Chipping at It



Tools & Environments Overview-1

Even with summarizing tools,
the amount of information that the requirements engineer must deal with is HUGE,

the number of relations between the individual items of information is HUGE^2, and

the number of relations between the individual relations is HUGE^4...

Tools & Environments Overview-2

So we want an environment filled with useful tools that help manage all the information needed to produce a requirements specification from the first conceptions, and then to be usable for the rest of the lifecycle.

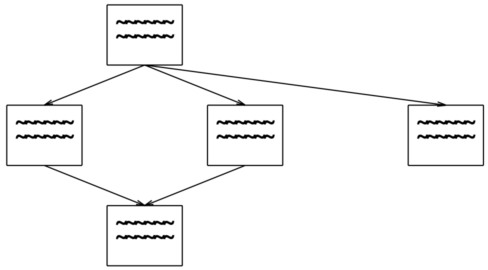
Tools & Environments Specifics-1

- **Graphical Issue-Based Information System (gIBIS) [Burgess-Yakemovic & Conklin 1990]**
- **Hypermedium as requirements engineering environments [Potts & Takahashi 1993, Kaindl 1993]**
- **Full spectrum, including traceability analysis, requirements engineering tool, READS [Smith 1993]**

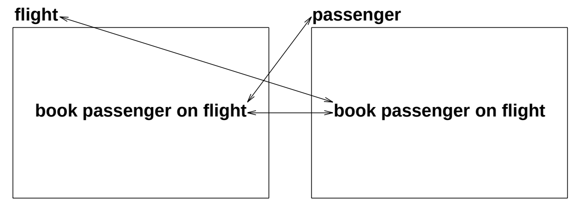
Tools & Environments Specifics-2

- **PRIME, KAOS for formal requirements modeling and analysis [Dardenne et al 1993]**
- **Multimedia hypermedium as requirements engineering environments [Wood, Christel & Stevens 1994]**
- **DOORS [Quality Systems and Software, Ltd.], icCONCEPT-RTM [Integrated Chipware], Requisite Pro [Rational], & other industrial requirements management platforms**

Some Views of Hypermedia Tools

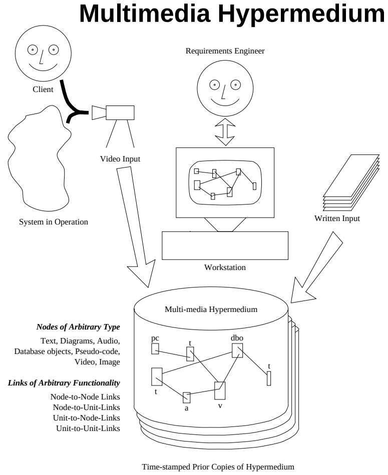


Network of Nodes



Links

Multimedia Hypermedium



Changes Overview-1

- **Change is the only thing that is permanent about software and requirements.**
- **Too many methods for RE (as for SE) assume incorrectly that the R (and the S) does not change, and these methods simply wilt under the face of the continual relentless changes that occur.**

Changes Overview-2

- Nowadays, a growing majority of the software we write is reworked legacy code, code that is too valuable to scrap, too difficult to modify or extend without error, too expensive to rebuild, but inadequate in its current form. RE for legacy software must deal with ripple effects on requirements that are largely unknown.

Changes Overview-3

- Configuration management and tracing are methods for dealing with changes in software, but they work only with the total cooperation of the people involved, people who generally disdain the regimentation required to use them. This drawback applies equally if not more so to configuration management and tracing of requirements.
- Prototyping is also a tool for controlled evolution of software and requirements.

Change Specifics

- General Software Configuration and Change Management [Carter, Martin, Mayblin & Munday 1984, Tichy 1985]
- Prototyping [Davis 1992]
- Traceability [Gotel & Finkelstein 1994]
- Inconsistency Management [Easterbrook & Nuseibeh 1995]
- Change Impact Analysis [Bohner & Arnold 1996]
- Combatting Requirements Creep [Berry 1998]

Empirical Studies Overview-1

- We have come to recognize that it is essential to test in actual industrial use those methods and tools that the research proposes, that it is not enough to declare that a method or tool should or must obviously work, that it is not enough to apply the method or tool to toy examples.

Empirical Studies Overview-2

- **We have also come to recognize that it is essential to observe industrial SE and RE in order to fully understand the problems faced by the practitioners, that it is not enough to theorize what must be their problem, or to decide for them what their problems are.**

Empirical Studies Specifics

- **User Participation in RE [El Aman, Quintin & Madhavji 1996]**
- **Inspections and RE [Kantorowitz, Guttmann & Arzi 1997]**

RE as a Human Activity Overview-1

Nuseibeh and Easterbrook remind us that the context in which RE takes place is usually a human activity system.

Therefore RE draws on other disciplines for help in understanding the process.

- **Cognitive Psychology: how people describe needs**
- **Anthropology: observations of human activities**

RE as a Human Activity Overview-2

- **Sociology: political & cultural changes**
- **Linguistics: RE requires clear communication in human languages**
- **Legal documents and requirements specifications have identical requirements: must anticipate all possible eventualities and contingencies and must be unambiguous**

RE as a Human Activity Overview-3

- **Philosophy**
  - **Epistemology: stakeholder beliefs**
  - **Phenomenology: real-world observations**
  - **Ontology: agreement on objective truths**

RE as a Human Activity Specifics

- **Linguistics [Knuth, Larrabee & Roberts 1989, Dupré 1998]**
- **Cognitive Psychology [Posner 1993]**
- **Anthrology [Goguen & Jirotka 1994b, Goguen & Linde 1993]**
- **Sociology [Holtzblatt & Beyer 1995, Beyer & Holtzblatt 1998]**
- **Ambiguity [Berry, Kamsties & Krieger 2000]**

Future

Lots more work is needed

Please join in!!

Recent Surveys

- **“Requirements Engineering: A Roadmap”, Nuseibeh & Easterbrook 2000**
- **“Requirements Engineering in the Year 00: A Research Perspective”, van Lamsweerde 2000**

Insightful Books

- ***Exploring Requirements: Quality Before Design*, Gause & Weinberg 1989**
- ***Are Your Lights On? How to Figure Out What the Problem REALLY Is*, Gause & Weinberg 1990**

Conferences and Workshops

- **International Workshop on Software Systems Design 1–11**
- **International Symposium on Requirements Engineering ’93, ’95, ’97 & ’99**
- **International Conference on Requirements Engineering ’94, ’96, ’98 & ’00**
- **IFIP WG 2.9 Software Requirements Engineering ’95, ’96, ’97 & ’99 & ’00**

Journals

- ***Software Practice and Experience***
- ***Journal of Systems and Software***
- ***IEEE Software***
- ***Journal of Automated Software Engineering***
- ***Requirements Engineering Journal***
- ***ACM Interactions***

Research Networks

- **RENOIR, Requirements Engineering Network Of International cooperating Research groups, a network of excellence sponsored by the European Union**

Web Pages

- **Requirements Engineering Newsletter (these are the files named renl*: ftp://ftp.cs.city.ac.uk/pub/requirements/**
- **Requirements Engineering Bibliography: http://www.inf.puc-rio.br/˜bdbib/**
- **RENOIR: http://www.cs.ucl.ac.uk/research/renoir/**