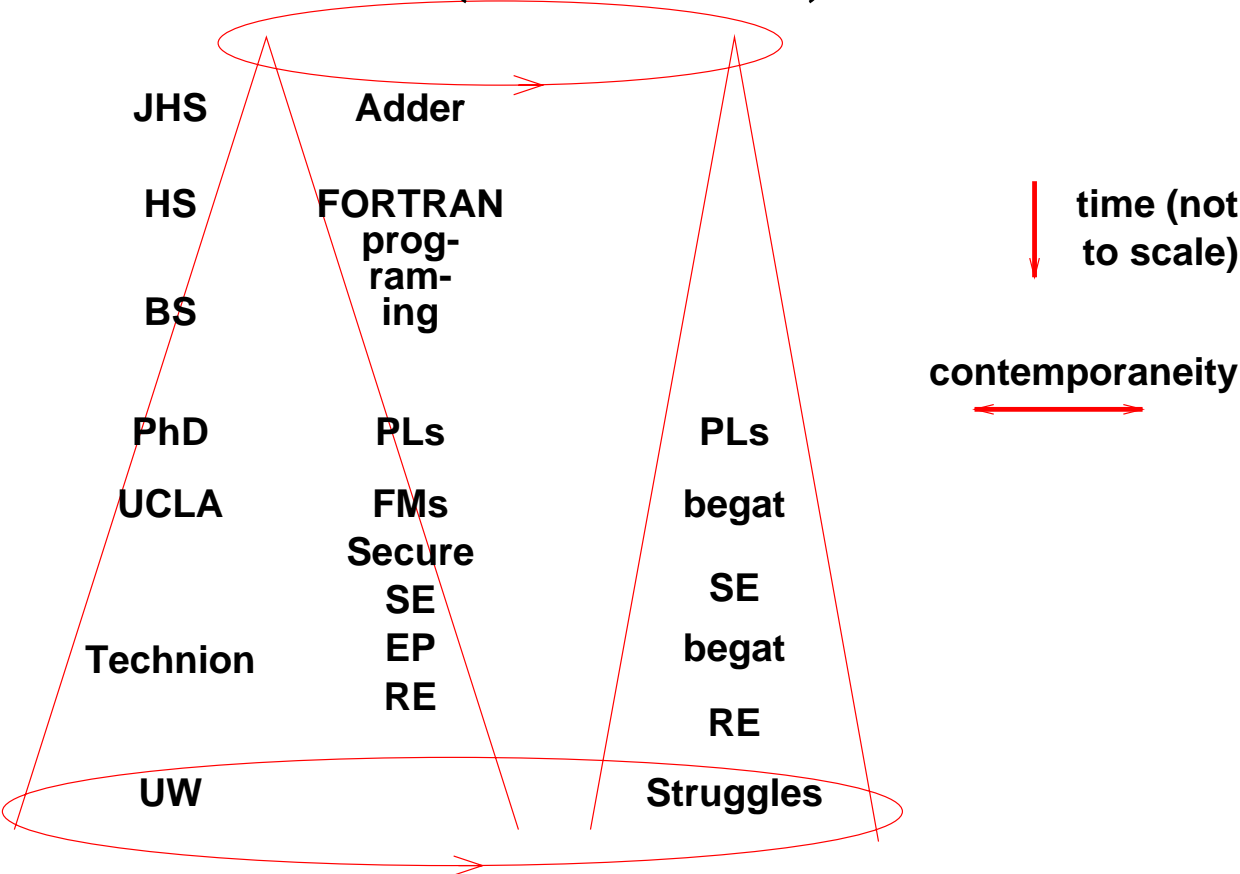


# The Prehistory and History of RE (+ SE) as Seen by Me: How My Interest in FMs Helped to Move Me to RE

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# Outline (Pictorial)



# About These Slides

**The full set of slides takes about 2 hours to go through, when you factor in all the jokes I think of and the questions you ask, 😊 !**

**For this talk, I have only  $X$  hours, and thus, the set of slides is trimmed.**

**You may find all trimmed sets and the full set at**

**`cs.uwaterloo.ca/~dberry/FTP_SITE/lecture.slides/HistoryOfMe_SE_FMs_RE/`**



# Foreword

**Please note that I *believed* in FMs.**

**I used them and still occasionally still use  
lightweight versions of them.**

# My Criticisms Are For Me

**When I criticize something, I am explaining what I observed that informed my own choice of what to work and to spend my *precious* time on.**

**I know that I may be wrong.**

**Therefore, I never criticize or disrespect another *person* for observing differently and choosing to work on what I don't work on.**

**Who knows, you might make a discovery that changes everything.**

# My Criticisms, Cont'd

**All the more power to you! Prove me wrong!**

**Granted, because of my observation, I believe that the probability of that happening is very low, ...**

**so I don't work in the same area.**

**But that could end up being *my* mistake!**

# Vocabulary

**CS = Computer Science**

**CBS = Computer-Based System**

**SW = Software**

**PL = Programming Language**

**FM = Formal Method**

**SE = Software Engineering**

**EP = Electronic Publishing**

**RE = Requirements Engineering**

# More Terminology

**We talk about methods, approaches, artifacts, and tools as technology that help us develop CBSs. I use “method” to stand for all of them so I don’t have to keep saying “method, approach, artifact, or tool” in one breath.**



# Overall Focus

**We will see that my focus has always been on writing correct and good SW, even while I have been in many different, SW-related fields.**

**My progression through PLs, FMs, Security, SE, and finally RE, has been to follow what I thought would help most to achieve that focus.**

**That is, when I specialized or shifted fields, it was because I thought the field I was in was not getting to the root of the problem.**

# We

**In the following, at any time, ...**

**“We” = all the people in whatever field I was in at the time.**

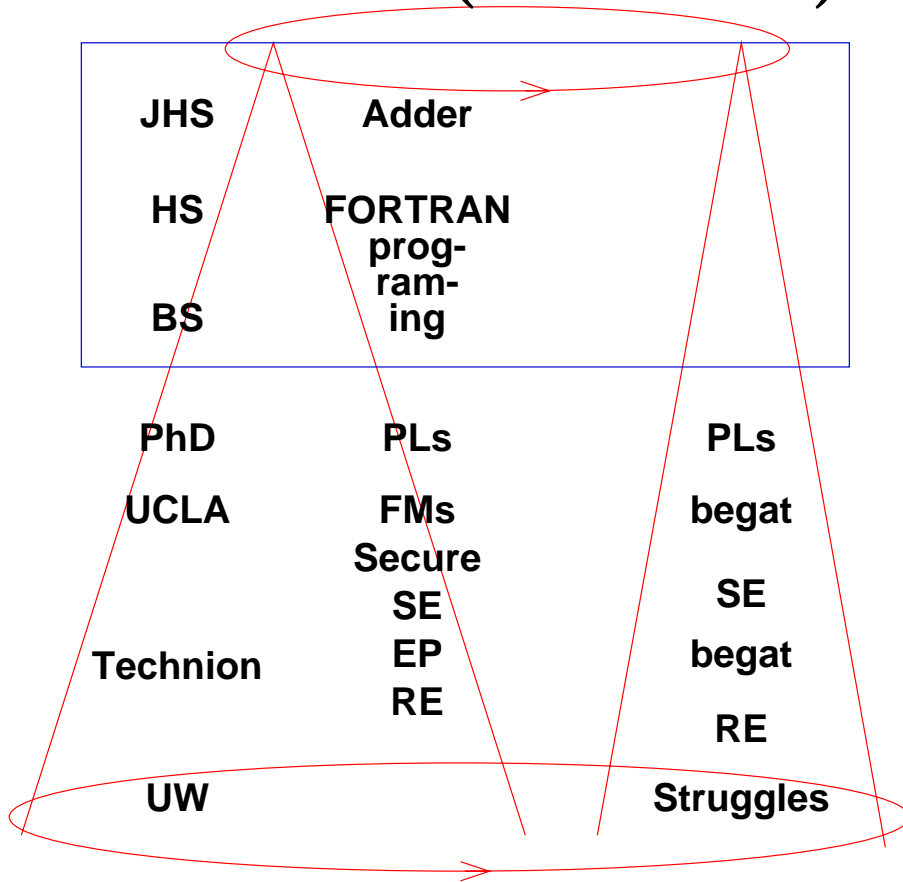
**So it is context dependent.**

**I use hats, e.g., , in the upper right hand corner of a slide to name the current context.**



1960s

# Outline (Pictorial)





# My 1960s Start in Computing

- **wrote my first real-life application, Operation Shadchan, a party 1-1 matching program based on the questionnaire of Operation Match, a 1- $n$  dating program, in the Spring of 1966, age 17, for my synagogue's youth group's annual party,**



# SOTP BIAFIUIW

**Through all this, I did seat-of-the-pants build-it-and-fix-it-until-it-works (SOTP BIAFIUIW) SW development, ...**

**simultaneous RE, design, and coding, ...**

**not really understanding the distinction between RE, design, and coding, ...**



# SOTP BIAFIUIW, Cont'd

**thinking that all of it were just parts of programming, ...**

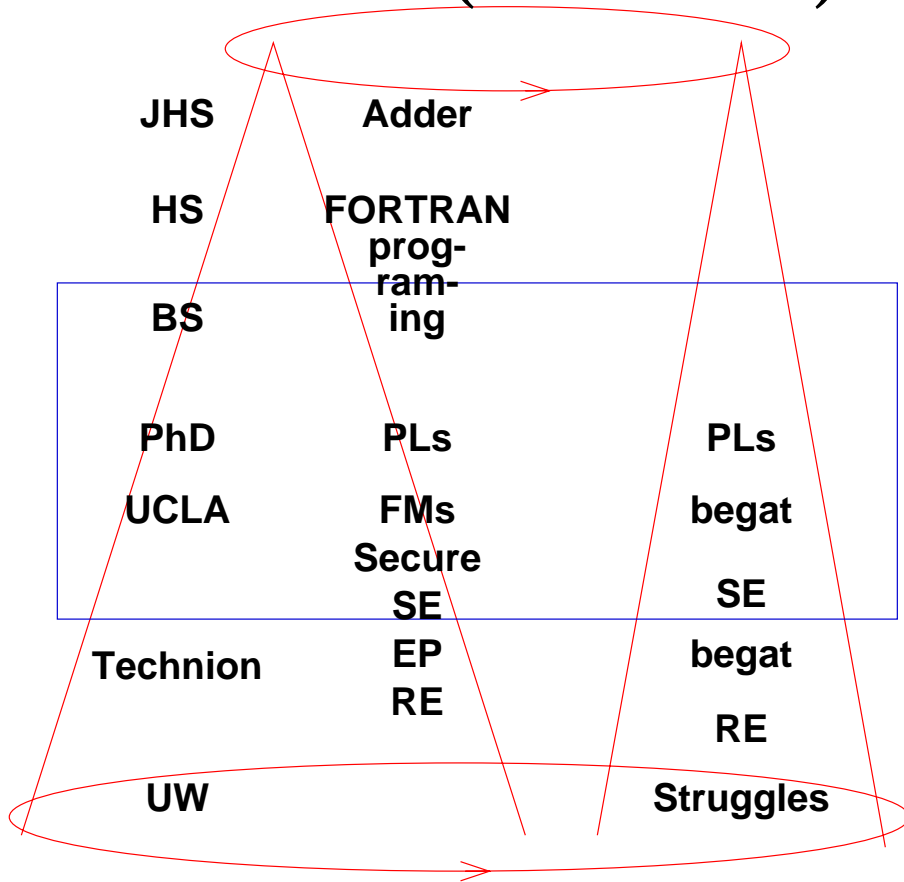
**probably like a whole lot of programmers, even professionals, did.**



1970s



# Outline (Pictorial)





# SARA

**All this time at UCLA, I was a member of Jerry Estrin's SARA group.**

**SARA was a multi-notation system design language, a competitor of SA and PSL/PSA, and ...**

**a FM based on data and control flow diagrams, and**

**a precursor of UML.**



# SARA, an Aside

You see, ...

**All of this work assumed that the requirements were GIVEN to you by the client on a silver platter, and the hard part was the specification and the analysis. It was only years later that we began to realize that getting the requirements to start with was the HARD part.**

# Mid '70s Foment in PL Area



**In the mean time, in the PL field, we realized that the key to getting better SW was *not* to improve PLs, *but* to improve the *process* of SW development.**



# Switching to SE

**So I, like a whole bunch of other PL people, ended up switching in the mid to late 1970s to SE.**

**We tried during the 1970s and 1980s (when ICSE met only every 18 months) to find methods, possibly assisted by math, to develop correct SW meeting its client's needs.**



# Morphing of Fields

**For these switchers, ...**

- **the study of PLs morphed to the study of SW development methods, and ...**
- **formal semantics for PLs morphed to FMs of SW development.**



# Security, Cont'd

**I consulted for the Formal Development Method (FDM) group of SDC (→ UNiSYS) that was working on secure operating systems, e.g., Blacker.**

**I ended up publishing a paper in *IEEE TSE* showing how the theorems that the group's verifier proved about an Ina Jo formal specification of a system were sufficient to prove that the system, if implemented as specified, would meet the specified criteria.**



# Security, Cont'd

**From all this work and from its community that included such people as Peter Neumann, I learned a lesson that goes right to the essence of RE:**

**There is no way to add security to any CBS after it is built; the desired security must be *required from the beginning* so that security considerations permeate the entire development lifecycle.**





# Beginning My Move to RE

**During this time, in 1981, I published a paper with Orna Berry about how I managed to do the best job ever in specifying software that she had to write, in a domain that I knew nothing about.**

**I agreed to do this job *only* because I was married to her at the time!**

# Ignorance Hiding



**I hid my ignorance of the statistics domain behind an abstract data type that she understood.**



# Importance of Ignorance

**By 1994, I figured out that the reason for the success was not the ignorance hiding, but the very ignorance!**



# Importance of ..., Cont'd

**So in 1994, I published “The Importance of Ignorance in RE” claiming that every RE team for a CBS requires along with domain (of the CBS) experts at least one smart ignoramus of the domain, who will**

- **provide out-of-the-box thinking that leads to creative ideas, and**
- **ask questions that expose tacit assumptions.**



# A Realization

**Then, a subset of the SE field came to the realization that the real problem plaguing CBS development was that we did not understand the requirements of the CBS we are building.**



# A Realization, Cont'd

**Brooks, in 1975, had said it well:**

**“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.”**



# Even a FMs Person Got it

**Even an initial-algebras, FMs person, Joe Goguen, came to this realization.**

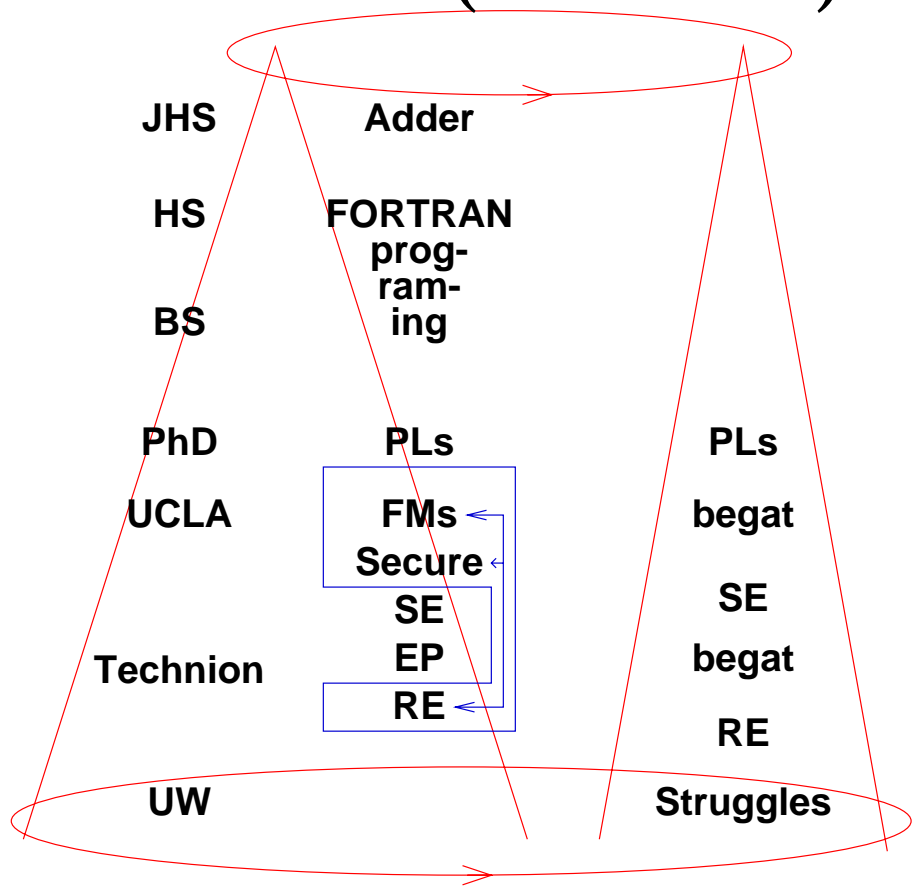
**He ended up being a keynoter at the first RE conference in 1993.**

# Fast Forward





# Outline (Pictorial)





# More About FM Part of My History

**I explore this part in greater depth.**

**First, what I noticed as it was happening.**

**Then, explaining some of it more formally.**

**Viewing FM from an RE lens!**



# Motivation to Write These Slides

**I am occasionally asked to referee a FMs  
paper, and**

**I occasionally hear a FMs talk.**



# Motivation, Cont'd

**I am struck by how little has changed from 1970s. I read or get a sense of:**

- **Here's a new approach to formalize  $X$ . ( $X$  is the same as in 1970s)**
- **If only developers would listen to us!**
- **We're on the verge of a breakthrough that will convince developers to use FMs.**

**It's all the same as in the 1970s and 1980s.**



# Never Change, Cont'd

**In my opinion, FMs will never be adopted by large numbers of CBS developers. Why?**

**Yes, there *have been* and there *are* breakthroughs in FMs, but these are not the only technological breakthroughs that affect programming.**



# Never Change, Cont'd

**With each breakthrough, all CBSs that needed this breakthrough to be implemented very quickly get implemented ...**

**CBSs that are left are even more difficult to implement.**



# Then What? Cont'd

**The problem with FMs is that because they are not the only breakthroughs, the gap between FMs and the difficult CBSs at the frontier gets bigger and bigger.**

**No technology, and in particular FMs, will ever catch up.**





# Unlike Some FMers

**I was always writing software for real-world applications:**

- **medium-sized CBSs by myself or with or by my students, and**
- **large-sized CBS as part of a team**



# Such as

- **matchmaking for a party (before knew about FMs)**
- **tools for regression analysis for chemists (before knew about FMs)**
- **bi-directional formatter**
- **proof updater for FDM suite of FM tools**
- **bi-directional editor**
- **tri-directional formatter**
- **letter stretching bi-directional formatter**



# Never Actually *Used* FMs

**I never even *considered* using FMs to develop any *real* SW ...**

**even for the proof updater for the FDM suite of FM tools.**

**Knowing what I knew about developing these systems, I would have been crazy to.**



# Never *Used* FMs, Cont'd

**Neither did Val Schorre and John Scheid in developing the other tools for the FDM suite, including a verification condition generator (VCG) for Ina Jo specs, and an interactive theorem prover (ITP).**

**(They did use Val's compiler-compiler to deal with the syntax.)**



# Never *Used* FMs, Cont'd

**Note that these tools *were* used in production applications of the FDM to building some half dozen verifiably secure systems at SDC for the US DOD and NSA.**



# Never *Used* FMs, Cont'd

**Apparently, neither did other developers of FM tools (at least the ones I knew).**

**This seemed to be one of the dirty, dark secrets among FM tool builders.**

**No one in his right mind would consider *using* FMs to build these tools.**

**The perception was that it would just take too long, and they might never finish.**



# FM's For Only Small Programs

**So, FM's could be used only for the development of *small* programs.**

**Operating system kernels and trusted system kernels *are* small programs.**

**So some FMers began a push to get all programs to be small!**



# Hoare on Small Programs

**Tony Hoare said (I think in late 1970s through 1980s),**

**“Inside every large program is a small program struggling to get out.”**

**I got in to the habit of trying to identify the central algorithm, the small program, at the heart of each of my programs.**

**Having done so, still the program was messy and the programming was hard.**





# Matchmaker

**I did this while I was in HS, long before I knew about FMs.**

**Later, it proved to be a variation of the stable marriage problem, with a 50-factor bi-directional attractiveness function, based on questionnaire answers.**

**In retrospect, the central formal model would have accounted for less than 5% of the code.**



# Matchmaker, Cont'd

**The rest of the code deals with**

- **incorrectly filled questionnaires,**
- **the complexities of having a mix of absolute criteria and do-the-best-that-you-can criteria, and**
- **having to deal with too-picky people who did not get matched by the algorithm, but still had to be matched for the party they paid for.**



# Back to the FDM ITP

**In retrospect, I can see why FMs were not used to develop the ITP.**

**The central, formal part of the ITP was a small fraction of its code.**

# Back to the FDM ITP, Cont'd



**The rest dealt with**

**implementing the really nice interaction with the user (the person trying to prove a theorem)**

**managing the current proof, including keeping track of what had been proved in a way that made it easy for a user to apply any of it at any time, ...**

**and this part is tough to formalize.**



# What vs. How Specifications

**Many times, it is much easier to express an algorithm to do something than to give an algorithm-independent description of what the something is:**

- **industrial processes**
- **exceptions to a central algorithm**
- **New York bagels (chewiness vs boil-then-bake)**



# Failings of FMs

**Even as FMs applied to Security taught me the fundamental essence of RE,**

**FMs have proved incapable of**

- **dealing adequately with the kinds of CBSs that we need to build, and**
- **doing what we need to do in RE.**

**We explore why.**



# FM's Not Deal With CBS's That We Build

**Let's see what Tony Hoare says.**

# Tony Hoare's Reversal, Cont'd



**“Ten years ago, researchers into formal methods (and I was the most mistaken among them) predicted that the programming world would embrace with gratitude every assistance promised by formalisation to solve the problems of reliability that arise when programs get large and more safety-critical. Programs have now got very large and very critical — well beyond the scale which can be comfortably tackled by formal methods.**



# Tony Hoare's Reversal, Cont'd



**There have been many problems and failures, but these have nearly always been attributable to inadequate analysis of requirements or inadequate management control. *It has turned out that the world just does not suffer significantly from the kind of problem that our research was originally intended to solve. [Italics are mine]***



# Hoare on Small Programs

**Tony Hoare once said (in mid 1970s),**

**“Inside every large program is a small program struggling to get out.”**

**Later (in early 2000s) he added,**

**“the small program can be found inside the large one only by ignoring the exceptions.”**

# Now I Understand



**Now I understand that what I was observing about the distribution of code is normal.**



# Distribution of Code

**10–20% of the code = central approximation.**

**80–90% of the code = exceptional details.**

**99.99% of execution time is spent in the central 10–20% of the code.**

**It's hard to test the exceptional details code, the 80–90% of the code, because it gets executed less than 0.01% of the execution time.**



# FMs Not Doing What RE Needs

**RE concerns validation more than verification,  
...**

**but FMs deal with ...**

# Verification, but ...

**FMs have the power to put**

**verifying the correctness of a CBS  
implementation w.r.t. its specifications**

**on a much firmer basis than is possible with**

**testing the CBS w.r.t. its specifications with  
well-chosen test data.**



**..., but Not Validation**

**However, this power does *very little* towards  
validating the specifications w.r.t. its  
customer's needs and wants,  
i.e., its customer's requirements.**



# And Here's Why

**The next bunch of slides are about what has become known as the Reference Model for Requirements and Specifications by Gunter, Gunter, Jackson, and Zave, or the RE Reference Model.**



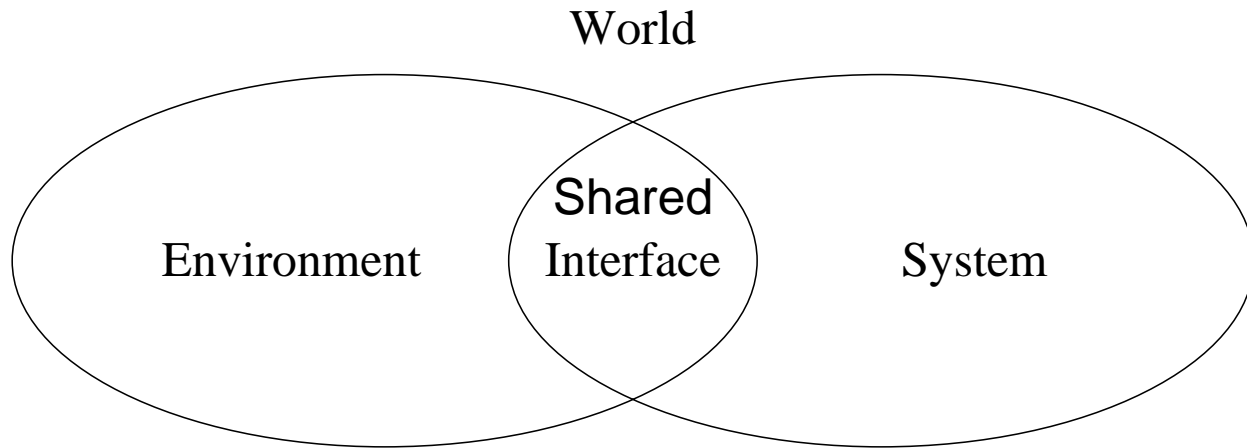


# The World and the CBS

**The world in which a CBS operates is divided into**

- **an Env, the environment affecting and affected by the CBS, and**
- **a Sys, the CBS itself, that intersect at their**
- **Intf, their Interface, and**
- **the rest of the world.**

# The World and the CBS





# Not Precise

**While Sys, the CBS, is formal (mathematical),**

**the rest of the world, including Env, is  
*hopelessly informal,***

**and the boundaries of Env are *hopelessly  
fuzzy:***

**Butterfly in Rio → Golden Gate Bridge**

**So finding all details to not ignore is hard.**



# Famous Validation Formula

The informality has been made formal in the Zave–Jackson Validation Formula (ZJVF):

$$D, S \vdash R$$

***D*** Domain Assumptions, in Env, informal

***S*** System Spec, in Intf, can be formal

***R*** Requirements, informal, in Env, informal

Truth of each of ***D*** and ***R*** in Env is *empirical*.



# **Sys Spec Formal?**

**S is formal, if it is about a program written in a PL.**

**If program is molecular, then even S is informal, and its truth is empirical.**

**If program uses machine learning, then S is effectively informal, and its truth is dependent on the learning set in ways that defy formalization.**



# Formal vs. Informal

**Michael Jackson [1995] once said:**

**“Requirements engineering is where the informal meets the formal.”**

- **Raw ideas: informal**
- **Code: formal**

# Informal Meets Formal

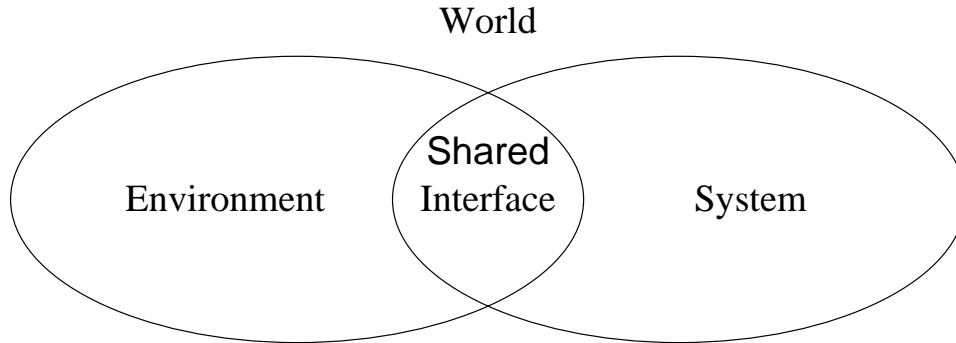


**Informality is unavoidable.**



# Where Are the Exceptions?

**From where is that 80–90% of the code = exceptional details?**



**From the Env, but not from the outside World!**

**But are we sure that it's not from the outside World?**





# Example: Airplane

**Sys = airplane**

**Env = the sky**

**World = everything not relevant**

**Are the following in the Env:**

- **flying bird?**
- **something in the hand of someone on the ground?**

**The boundaries of Env are *hopelessly fuzzy*.**



# Two Types of Requirements

**There are two types of requirements:**

- 1. scope determining**
- 2. scope determined**

**E.g., for a pocket calculator with  $+$ ,  $-$ ,  $\times$ ,  $\div$ ,**

- 1.  $\ln$  and  $x^y$ , are scope-determining requirements.**
- 2. “that  $d \neq 0$  in  $n \div d$ ” is a scope-determined requirement.**



# Difference Between Types

**A pocket calculator without one particular scope determining requirement is just a less useful and less attractive calculator.**

**A pocket calculator without one particular scope determined requirement is a flawed calculator, which will give the wrong result or fail for some inputs.**



# FMs and the Two Types

**FMs help discover scope-determined requirements.**

**FMs offer little help discovering scope-determining requirements, ...**

**because each scope-determining requirement is independent of the others.**

**“If no one happens to think of it, it just ain’t gonna be there.”**

# Value of RE Reference Model



**The RE RM has become extremely valuable as  
a ...**

**lightweight, informal version of a FM ...**

**that is able to answer many questions that  
come up during RE for a CBS.**



# Value of RE RM, Cont'd

**The RE RM is used to help**

- **partition the World, i.e., to decide for each of Env, Intf, and Sys, what is in it and is not, ...**

**sometimes to shuffle an entity among Env, Intf, and Sys**



# Value of RE RM, Cont'd

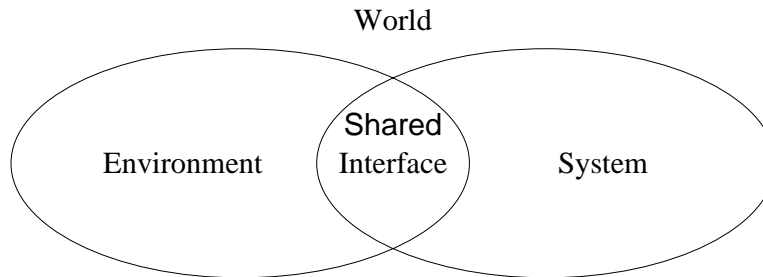
- decide *What vs. How*:

***What*** is in the vocabulary of Env

***S*** is in the vocabulary of Intf

***R*** is in the vocabulary of Env

***How*** is in the vocabulary of Sys–Intf





# Value of RE RM, Cont'd

- **permanently tolerate an inconsistency  $I$  between  $R$  and  $S$  and the World,**

**by lying in  $D$  that  $I$  is not a problem, ...**

**e.g., for the Airplane CBS, permanently tolerate that a bird's meeting an airplane in the air can crash the airplane, by lying in  $D$  that there are no birds in the air.**





# Important Fact

**Remember that a program itself is a formal specification.**

**The programming language is a formally defined language with precise semantics just like Z, in fact, even more so than Z, which purposely leaves some things undefined.**

**One could not *prove* the consistency of specifications and code if code were not formal!**



# Programming as a FM

**Programming itself is a FM in the sense that writing a formal specification is a FM!**

**Remember that programming is building a theory from the programming language and library of abstractions (the ground) up, just like making new mathematics.**

**But there are some fundamental differences between a program and a math model, as it's usually done.**



# Math Model vs. Program

**Each is a model of the real world.**

**Different audience:**

- **math model read by smart human; can deal with “YUWIM”**
- **program read by dumb computer; cannot deal with “YUWIM”**



# Math vs. Program, Cont'd

**Because of difference in audience,**

- **math model can get away with simplifications and approximations for tractability;**
- **program must deal with every detail, with *no approximation*, or else program fails at exception conditions, e.g., plane crashes.**



# Fickas on Outliers

**Steve Fickas once said,**

**“Sciences ignore outliers.”**

**But, robust software cannot.**

# Central Math Model in Code



**In a program based on a mathematical model of some real-world phenomenon, ...**

**the mathematical model amounts to 20% of the code, and the code to deal with the outliers, the approximations, the exceptions, etc. amounts to 80% of the code.**



# Code as Math Model

**So, code is a much more complete mathematical model than most mathematical models produced by mathematicians or scientists.**

**Even then, as we saw with the World Model and the ZJVF, it cannot be a *perfect* model.**

# What *Does* Work?



**Good people, not good methods!**





# Success Stories of FMs

**The typical success story describes a FM person convincing a project to apply some particular FM.**

**The deal is that the FM person joins the team and either does or leads the formalization effort.**



# Success Stories, Cont'd

**The reported experience shows the FM person slowly learning the domain from the experts by asking lots of questions and making lots of mistakes.**

**The end result is that the application of the FM found many significant problems earlier and the whole development was cheaper, faster, etc. than expected.**



# Real Value of FMs

**Perhaps the real value of FMs is that they attract really good people, the FMers, who is good at dealing with abstractions, who is good at modeling, etc., the **smart ignoramus**, into working on the development of your CBS.**

**Managers know that the success of a CBS development project depends more on personnel issues than on technological issues.**



# Flawed Experiment

**“Formal Methods Application: An Empirical Tale of Software Development”, by Ann E. K. Sobel and Michael R. Clarkson, *IEEE Transactions on Software Engineering* 28:3, 157–161, March 2002**

**Attempt to empirically prove the effectiveness of FMs in producing quality software.**



# **FMs vs. No FMs**

**They arranged two groups of teams of university students**

**Each team in group number**

- 1. learned FMs and used them in a term-long project to develop a program**
- 2. did not learn FMs and did term-long project to develop same program**



# Results

- 1. 100% of programs produced by FM teams passed all of a set of 6 test cases.**
- 2. Only 45.5% of programs produced by nonFM teams passed all of same set of test cases.**

**Wow!!**



# Conclusions

## **Sobel and Clarkson's Conclusions:**

**Since teams did not differ by all sorts of academic measures, the successes were due to the use of FMs**



# Wrong!

**Walter Tichy and I independently spotted the flaw in the experiment (We ended up writing a joint note).**

## **Voluntary Selection!**

**Only students who had voluntarily taken an optional course on FMs were in FMs teams.**

**NonFM teams consisted of only students who had *not* taken this FMs course.**





# No Control

**Also, there was *no* control over whether the FM teams actually *used* FMs in the development.**

**Might be that the FM teams took advantage of skills, e.g., abstracting, logical thinking, etc., used in FMs, to improve their programming without actually doing any FM.**

**Not enough information to know.**



# Alternative Explanation

**Berry and Tichy offered an alternative theory for results:**

**The reason for the success was presence of the people who were interested in, and presumably skilled in, in FMs, abstract thinking, etc.**

**They program better naturally!**



# Alternative ..., Cont'd

**The teams consisting of FMs users, whose programs passed all the tests, were just plainly and simply *better programmers* than the teams not containing any FMs users, whose programs did not pass all the tests.**

**No surprise there!**



# Lesson Learned

**Good FMers make good programmers.**

**So if you're managing a SW development, hire FMers to be your programmers!**



# My Message to FMers

**Forget about proving programs, i.e., code, correct; it's not cost effective:**

- **it increases development cost by an order of magnitude;**
- **only 15–25% of all errors are introduced by coding; and**
- **numerous experiments show that inspection does a good job of eliminating coding errors for only 15% overhead.**



# My Message, Cont'd

**Focus on getting correct & complete requirements specs, where 75–85% of the errors occur:**

- **FMs applied to make the specs more correct, i.e., to eliminate errors of commission & discover missing scope *determined* requirements**
- **FMer applied to make the specs more complete, i.e., to eliminate errors of omission & discover new scope *determining* requirements**