CSE503: Software Engineering

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Software evolution
(recap from intro lectures)

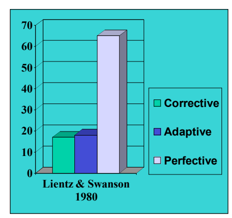
- Software changes
  - Software maintenance
  - Software evolution
  - Incremental development
- The objective is to use an existing code base as an *asset*
  - Cheaper and better to get there from here, rather than starting from scratch
  - Anyway, where would you aim for with a new system?

Why does it change?

- Software changes does not change primarily because it doesn't work right
  - Maintenance in software is different than maintenance for automobiles
- But rather because the technological, economic, and societal environment in which it is embedded changes
- This provides a feedback loop to the software
  - The software is usually the most malleable link in the chain, hence it tends to change
    - Counterexample: Space shuttle astronauts have thousands of extra responsibilities because it's safer than changing code

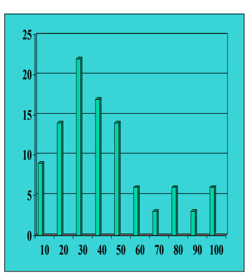
Kinds of change

- Corrective maintenance
  - Fixing bugs in released code
- Adaptive maintenance
  - Porting to new hardware or software platform
- Perfective maintenance
  - Providing new functions
- Old data, focused on IT systems…now?



High cost, long time

- Gold's 1973 study showed the fraction of programming effort spent in maintenance
- For example, 22% of the organizations spent 30% of their effort in maintenance



Total life cycle cost

- Lientz and Swanson determined that at least 50% of the total life cycle cost is in maintenance
- There are several other studies that are reasonably consistent
- General belief is that maintenance accounts for somewhere between 50-75% of total life cycle costs

Open question

- How much maintenance cost is “reasonable?”
  - Corrective maintenance costs are ostensibly not “reasonable”
  - How much adaptive maintenance cost is “reasonable”?
  - How much perfective maintenance cost is “reasonable”?
- Measuring “reasonable” costs in terms of percentage of life cycle costs doesn’t make sense

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High-level answer

- For perfective maintenance, the objective should be for the cost of the change in the implementation to be proportional to the cost of the change in the specification (design)
  - Ex: Allowing dates for the year 2000 is (at most) a small specification change
  - Ex: Adding call forwarding is a more complicated specification change
  - Ex: Converting a compiler into an ATM machine is …

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Question: relationship of reuse to evolution?

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(Common) Observations

- Maintainers often get less respect than developers
- Maintenance is generally assigned to the least experienced programmers
- Software structure degrades over time
- Documentation is often poor and is often inconsistent with the code

- Is there any relationship between these?

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Laws of Program Evolution
Program Evolution: Processes of Software Change (Lehman & Belady)

- Law of continuing change
- “A large program that is used undergoes continuing change or becomes progressively less useful.”
  - Analogies to biological evolution have been made; the rate of change in software is generally far faster
- P-type programs
  - Well-defined, precisely specified
  - The challenge is efficient implementation
  - Ex: sort
- E-type programs
  - Ill-defined, fit into an ever-changing environment
  - The challenge is managing change
- Also, S-type programs
  - Ex: chess

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Law of increasing complexity

- “As a large program is continuously changed, its complexity, which reflects deteriorating structure, increases unless work is done to maintain or reduce it.”
  - Complexity, in part, is relative to a programmer’s knowledge of a system
    - Novices vs. experts doing maintenance
  - Cleaning up structure is done relatively infrequently
    - Even with the recent interest in refactoring, this seems true. Why?

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Reprise

- The claim is that if you measure any reasonable metric of the system
  - Modules modified, modules created, modules handled, subsystems modified, …
- and then plot those against time (or releases)
- Then you get highly similar curves regardless of the actual software system
- A zillion graphs on http://www.doc.ic.ac.uk/~mml/feast1/

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Statistically regular growth

- "Measures of [growth] are cyclically self-regulating with statistically determinable trends and invariances."
  - (You can run but you can't hide)
    - There's a feedback loop
  - Based on data from OS/360 and some other systems
  - Ex: Content in releases decreases, or time between releases increases
- Is this related to Brooks' observation that adding people to a late project makes it later?

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And two others

- "The global activity rate in a large programming project is invariant."
- "For reliable, planned evolution, a large program undergoing change must be made available for regular user execution at maximum intervals determined by its net growth."
  - This is related to "daily builds"

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Open question

- Are these "laws" of Belady and Lehman actually inviolable laws?
- Could they be overcome with tools, education, discipline, etc.?
- Could their constants be fundamentally improved to give significant improvements in productivity?
  - Within the past few years, Alan Greenspan and others have claimed that IT has fundamentally changed the productivity of the economy: "The synergistic effect of new technology is an important factor underlying improvements in productivity."

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Approaches to reducing cost

- Design for change (proactive)
  - Information hiding, layering, open implementation, aspect-oriented programming, etc.
- Tools to support change (reactive)
  - grep, etc.
  - Reverse engineering, program

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Approaches to reducing cost

- Improved documentation (proactive)
  - Discipline, stylized approaches
  - Parnas is pushing this *very* hard, using a tabular form of specifications
  - Literate programming
- Reducing bugs (proactive)
  - Many techniques, some covered later in the quarter
- Increasing correctness of specifications (proactive)
- Others?

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Program understand & comprehension

- Definition: The task of building *mental models* of the underlying software at various abstraction levels, ranging from models of the code itself to ones of the underlying application domain, for maintenance, evolution, and re-engineering purposes [H. Müller]

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Various strategies

- Top-down
  - Try to map from the application domain to the code
- Bottom-up
  - Try to map from the code to the application domain
- Opportunistic: mix of top-down and bottom-up

- I'm not a fan of these distinctions, since it has to be opportunistic in practice
  - Perhaps with a *really* rare exception

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Did you try to understand?

- "The ultimate goal of research in program understanding is to improve the process of comprehending programs, whether by improving documentation, designing better programming languages, or building automated support tools." —Clayton, Rugaber, Wills
- To me, this definition (and many, many similar ones) miss a key point: What is the programmer's task?
- Furthermore, most good programmers seem to be good at knowing what they need to know *and what they don't need to know*

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A scenario

- I'll walk through a simple scenario or two
- The goal isn't to show you "how" to evolve software
- Rather, the goal is to try to increase some of the ways in which you think during software evolution

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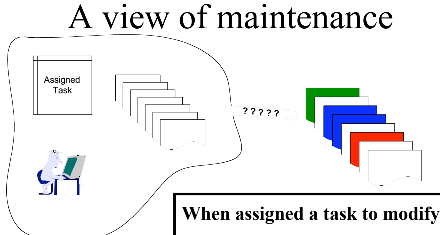
A view of maintenance



When assigned a task to modify an existing software system, how does a software engineer choose to proceed?

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Sample (simple) task

- You are asked to update an application in response to a change in a library function
- The original library function is
  - `assign(char* to, char* from, int cnt = NCNT)`
  - Copy `cnt` characters from `to` into `from`
- The new library function is
  - `assign(char* to, char* from, int pos, int cnt = NCNT)`
  - Copy `cnt` characters starting at `pos` from `to` into `from`
- How would you make this change?

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Recap: example

- What information did you need?
- What information was available?
- What tools produced the information?
  - Did you think about other pertinent tools?
- How accurate was the information?
  - Any false information? Any missing true information?
- How did you view and use the information?
- Can you imagine other useful tools?

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Source models

- Reasoning about a maintenance task is often done in terms of a model of the source code
  - Smaller than the source, more focused than the source
- Such a *source model* captures one or more relations found in the system's artifacts
  - There are many possible relations: calls, uses, registers-interest-in, names, #includes, inherits-from, etc.

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Extracting source models

- Source models are extracted using tools
- Any source model can be extracted in multiple ways
  - That is, more than one tool can produce a given kind of source model
- The tools are sometimes off-the-shelf, sometimes hand-crafted, sometimes customized

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Information characteristics

	no false positives	*false positives*
no false negatives	ideal	conservative
false negatives	optimistic	approximate

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Ideal source models

- It would be best if every source model extracted was perfect
  - All entries are true and no true entries are omitted
- For some source models, this is possible
  - Inheritance, defined functions, `#include` structure, etc.
- For some source models, achieving the ideal may be difficult in practice
  - Ex: computational time is prohibitive in practice
- For many other interesting source models, this is not possible
  - Ideal call graphs, for example, are uncomputable

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Conservative source models

- These include all true information and maybe some false information, too
- Frequently used in compiler optimization, parallelization, in programming language type inference, etc.
  - Ex: never misidentify a call that can be made or else a compiler may translate improperly
  - Ex: never misidentify an expression in a statically typed programming language

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Optimistic source models

- These include only truth but may omit some true information
- Often come from dynamic extraction
- Ex: In white-box code coverage in testing
  - Indicating which statements have been executed by the selected test cases
  - Others statements may be executable with other test cases

Approximate source models

- May include some false information and may omit some true information
- These source models can be useful for maintenance tasks
  - Especially useful when a human engineer is using the source model, since humans deal well with approximation
  - It's "just like the web!"
- Turns out many tools produce approximate source models

Static vs. dynamic

- Source model extractors can work
  - *statically*, directly on the system's artifacts, or
  - *dynamically*, on the execution of the system, or
  - a combination of both
- Ex:
  - A call graph can be extracted statically by analyzing the system's source code or can be extracted dynamically by profiling the system's execution

Must iterate

- Usually, the engineer must iterate to get a source model that is "good enough" for the assigned task
- Often done by inspecting extracted source models and refining extraction tools
- May add and combine source models, too

Another maintenance task

- Given a software system, rename a given variable throughout the system
  - Ex: `angle` should become `diffraction`
  - Probably in preparation for a larger task
- Semantics must be preserved
- This is a task that is done infrequently
  - Without it, the software structure degrades more and more

What source model?

- Our preferred source model for the task would be a list of lines (probably organized by file) that reference the variable `angle`
- A static extraction tool makes the most sense
  - Dynamic references aren't especially pertinent for this task

Start by searching

- Let's start with grep, the most likely tool for extracting the desired source model
- The most obvious thing to do is to search for the old identifier in all of the system's files
  - `grep angle *`

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What files to search?

- It's hard to determine which files to search
  - Multiple and recursive directory structures
  - Many types of files
    - Object code? Documentation? (ASCII vs. non-ASCII?) Files generated by other programs (such as yacc)? Makefiles?
  - Conditional compilation? Other problems?
- Care must be taken to avoid false negatives arising from files that are missing

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False positives

- `grep angle` *`[system's files]`*
- There are likely to be a number of spurious matches
  - `…triangle…, …quadrangle…`
  - `/* I could strangle this programmer! */`
  - `/* Supports the small planetary rovers presented by Angle & Brooks (IROS '90) */`
  - `printf("Now play the Star Spangled Banner");`
- Be careful about using `agrep`!

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More false negatives

- Some languages allow identifiers to be split across line boundaries
  - Cobol, Fortran, PL/I, etc.
  - This leads to potential false negatives
- Preprocessing can hurt, too
  - ```
    #define deflection angle
    ...
    deflection = sin(theta);
    ```

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It's not just syntax

- It is also important to check, before applying the change, that the new variable name (`degree`) is not in conflict anywhere in the program
  - The problems in searching apply here, too
  - Nested scopes introduce additional complications

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Tools vs. task

- In this case, `grep` is a lexical tool but the renaming task is a semantic one
  - Mismatch with syntactic tools, too
- Mismatches are common and not at all unreasonable
  - But it does introduce added obligations on the maintenance engineer
  - Must be especially careful in extracting and then using the approximate source model

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    ```

Finding vs. updating

- Even after you have extracted a source model that identifies all of (or most of) the lines that need to be changed, you have to change them
- Global replacement of strings is at best dangerous
- Manually walking through each site is time-consuming, tedious, and error-prone

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Downstream consequences

- After extracting a good source model by iterating, the engineer can apply the renaming to the identified lines of code
- However, since the source model is approximate, regression testing (and/or other testing regimens) should be applied

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Griswold's approach

- Griswold developed an approach to meaning-preserving restructuring
- Make a local change
  - The tool finds global, compensating changes that ensure that the meaning of the program is preserved
    - What does it mean for two programs to have the same meaning?
  - If it cannot find these, it aborts the local change

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Simple example

- Swap order of formal parameters

```
procedure push(s, v)
  insert(v, s.head)
  return s
end
 .
 .
 .
push(myStack,1)
 .
 .
 .
push(myStack,h(myStack))
```

- It's not a local change nor a syntactic change
- It requires semantic knowledge about the programming language
- Griswold uses a variant of the sequence-congruence theorem [Yang] for equivalence
  - Based on PDGs (program dependence graphs)
- It's an O(1) tool
  - The user touches only one place

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Limited power

- The actual tool and approach has limited power
- Can help translate one of Parnas' KWIC decompositions to the other
- Too limited to be useful in practice
  - PDGs are limiting
    - Big and expensive to manipulate
    - Difficult to handle in the face of multiple files, etc.
- May encourage systematic restructuring in some cases
- Some related work specifically in OO by Opdyke and Johnson
- Question: How do you find appropriate restructuring?

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Star diagrams [Griswold et al.]

- Meaning-preserving restructuring isn't going to work on a large scale
- But sometimes significant restructuring is still desirable
- Instead provide a tool (star diagrams) to
  - record restructuring plans
  - hide unnecessary details
- Some modest studies on programs of 20-70KLOC

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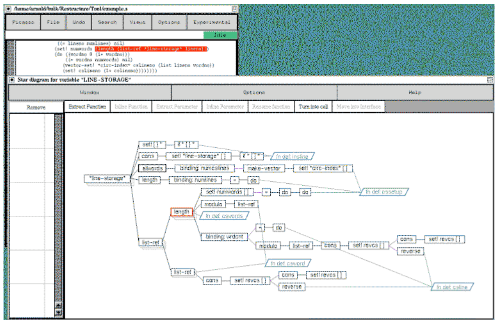
A star diagram



Interpreting a star diagram

- The root (far left) represents all the instances of the variable to be encapsulated
- The children of a node represent the operations and declarations directly referencing that variable
- Stacked nodes indicate that two or more pieces of code correspond to (perhaps) the same computation
- The children in the last level (parallelograms) represent the functions that contain these computations

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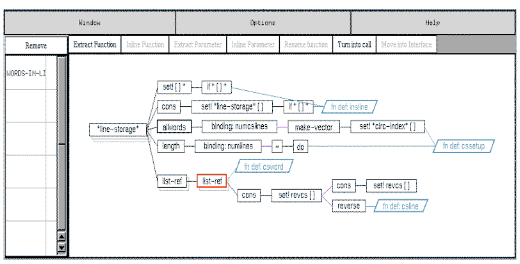
After some changes



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Evaluation

- Compared small teams of programmers on small programs
  - Used a variety of techniques, including videotape
  - Compared to vi/grep/etc.
- Nothing conclusive, but some interesting observations including
  - The teams with the star diagram tools adopted simpler strategies for handling completeness and consistency

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My view

- Star diagrams may not be “the” answer
- But I like the idea that they encourage people
  - To think clearly about a maintenance task, reducing the chances of an *ad hoc* approach
  - They help track mundane aspects of the task, freeing the programmer to work on more complex issues
  - To focus on the source code

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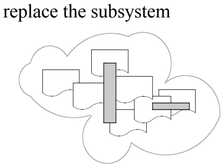
Another task: isolating a subsystem

- Many maintenance tasks require identifying and isolating functionality within the source
  - sometimes to extract the subsystem
  - sometimes to replace the subsystem



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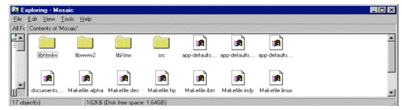
Mosaic

- The task is to isolate and replace the TCP/IP subsystem that interacts with the network with a new corporate standard interface
- First step in task is to estimate the cost (difficulty)

Mosaic source code



- After some configuration and perusal, determine the source of interest is divided among 4 directories with 157 C header and source files
- Over 33,000 lines of non-commented, non-blank source lines

Some initial analysis

- The names of the directories suggest the software is broken into:
  - code to interface with the X window system
  - code to interpret HTML
  - two other subsystems to deal with the world-wide-web and the application (although the meanings of these is not clear)

Extract some potentially useful source models

static function references (CIA)	3966
static function-global var refs (CIA)	541
dynamic function calls (gprof)	1872
Total	6379

- We are still left with a fundamental problem: how to deal with one or more large source models?

One approach

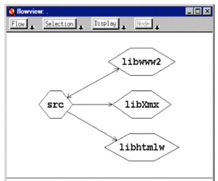
- Use a query tool against the source model(s)
  - For instance, grep
- As necessary, consult source code
  - "It's the source, Luke."
  - Mark Weiser. Source Code. IEEE Computer 20,11 (November 1987)

Other approaches

- Visualization
- Reverse engineering
- Summarization

Visualization

- e.g., Field, Plum, Imagix 4D, McCabe, etc.
  (Field's flowview is used above and on the next few slides...)
- Note: several of these are commercial products



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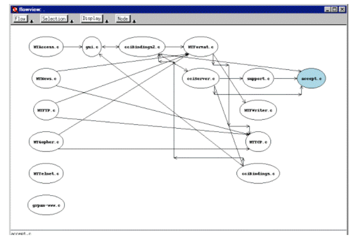
Visualization...



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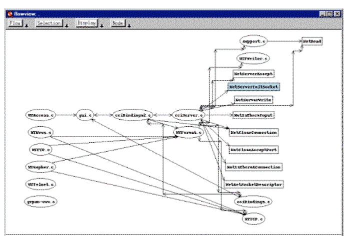
Visualization...



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Visualization...

- Provides a "direct" view of the source model
- View often contains too much information
  – Use elision (…)
  – With elision you describe what you are not interested in, as opposed to what you are interested in

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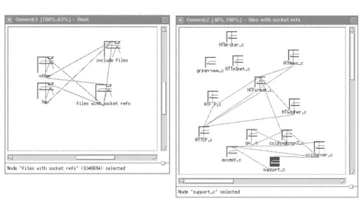
Reverse engineering



- e.g., Rigi, various clustering algorithms
  (Rigi is used above)

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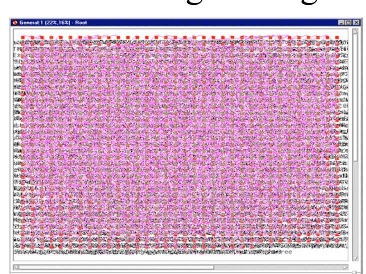
Reverse engineering...



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Clustering

- The basic idea is to take one or more source models of the code and find appropriate clusters that might indicate “good” modules
- Coupling and cohesion, of various definitions, are at the heart of most clustering approaches
- Many different algorithms

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Rigi’s approach

- Extract source models
- Build edge-weighted flow graphs over these models
  - Discrete sets on the edges, representing the resources that flow from source to sink
- Compose these to represent subsystems
  - Looking for strong cohesion, weak coupling
- The papers define interconnection strength and similarity measures (with tunable thresholds)

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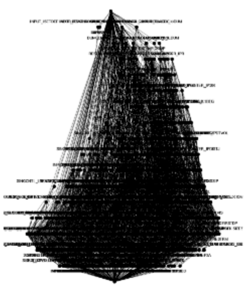
An aerodynamics program

- Based on mathematical concept analysis
- 106KLOC Fortran
- 20 years old
- 317 subroutines
- 492 global variables
- 46 COMMON blocks



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Reverse engineering recap

- Generally produces a higher-level view that is consistent with source
- Sometimes view still contains too much information leading again to the use of techniques like elision

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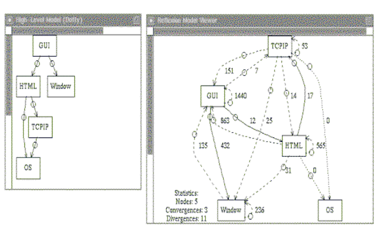
Summarization



- e.g., software reflexion models

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Summarization...

- A map file specifies the correspondence between parts of the source model and parts of the high-level model

```
[ file=HTTCP        mapTo=TCPIP ]
[ file=^SGML        mapTo=HTML ]
[ function=socket   mapTo=TCPIP ]
[ file=accept       mapTo=TCPIP ]
[ file=cci          mapTo=TCPIP ]
[ function=connect  mapTo=TCPIP ]
[ file=Xm           mapTo=Window ]
[ file=^HT          mapTo=HTML ]
[ function=.*       mapTo=GUI ]
```

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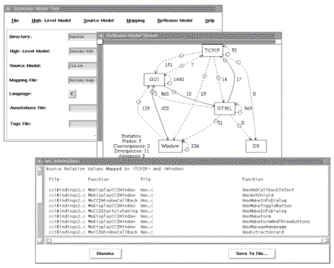
Summarization...



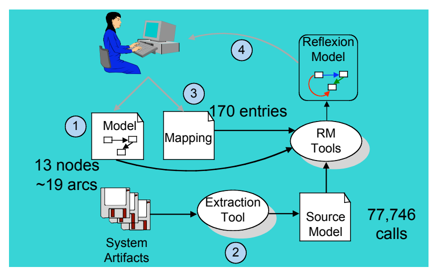
Summarization...

- Condense (some or all) information in terms of a high-level view quickly
  - In contrast to visualization and reverse engineering, produce an “approximate” view
  - Iteration can be used to move towards a “precise” view
- Some evidence that it scales effectively
- May be difficult to assess the degree of approximation

Case study: A task on Excel

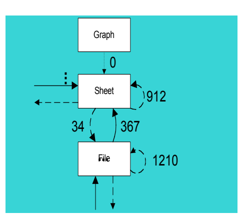
- A series of approximate tools were used by a Microsoft engineer to perform an experimental reengineering task on Excel
- The task involved the identification and extraction of components from Excel
- Excel (then) comprised about 1.2 million lines of C source
  - About 15,000 functions spread over ~400 files

The process used



An initial Reflexion Model

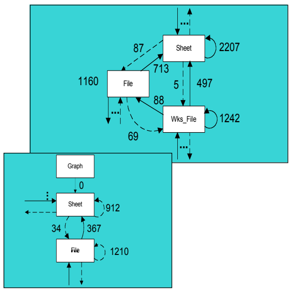
- The initial Reflexion Model computed had 15 convergences, 83, divergences, and 4 absences
- It summarized 61% of calls in source model



An iterative process

- Over a 4+ week period
- Investigate an arc
- Refine the map
  - Eventually over 1000 entries
- Document exceptions
- Augment the source model
  - Eventually, 119,637 interactions

A refined Reflexion Model



- A later Reflexion Model summarized 99% of 131,042 call and data interactions
- This approximate view of approximate information was used to reason about, plan and automate portions of the task

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Results

- Microsoft engineer judged the use of the Reflexion Model technique successful in helping to understand the system structure and source code

  "Definitely confirmed suspicions about the structure of Excel. Further, it allowed me to pinpoint the deviations. It is very easy to ignore stuff that is not interesting and thereby focus on the part of Excel that I want to know more about." — Microsoft A.B.C. (anonymous by choice) engineer

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Which ideas are important?

- Source code, source code, source code
- Task, task, task
  - The programmer decides where to increase the focus, not the tool
- Iterative, pretty fast
- Doesn't require changing other tools nor standard process being used
- Text representation of intermediate files
- A computation that the programmer fundamentally understands
  - Indeed, could do manually, if there was only enough time
- Graphical may be important, but also may be overrated in some situations

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Summary

- Evolution is done in a relatively ad hoc way
  - Much more ad hoc than design, I think
- Putting some intellectual structure on the problem might help
  - Sometimes tools can help with this structure, but it is often the intellectual structure that is more critical

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