CSE584: Software Engineering

Lecture 8: Tools & Analysis (A)

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This week and next

- Tools and analysis
  - Some discussion of integrated environments (IDEs, CASE), too
- In some ways, the analysis part might be close to the specification topics covered earlier in the quarter
- But the focus will be much, much closer to the source code

Structure

- Some overview on tools
- Some discussion on integrated environments
- Static vs. dynamic tools
- Underlying representations
  - Slicing will be the example tool
- Example tools

What's a tool?

- Merriam-Webster
  - a handheld device that aids in accomplishing a task; the cutting or shaping part in a machine or machine tool; a machine for shaping metal
- From Jargon File (4.0.0/24 July 1996)
  - A program used primarily to create, manipulate, modify, or analyze other programs, such as a compiler or an editor of a cross-referencing program
    - For these lectures, I will omit "intellectual" tools, focusing instead on this kind of tool

What's analysis?

- Merriam-Webster
  - an examination of a complex, its elements, and their relations
- What do I mean (for these lectures)?
  - Computer-supported "reasoning" that is intended to aid a programmer in understanding and improving a software system

One thing I learned is that psychoanalysts don't have much of a sense of humor

You try to find a picture of a person laying on a couch talking to a psychoanalyst somewhere on the web!

Tools you probably use

- Compilers
- Editors
- Debuggers
  - How often?
- Profilers
  - How often?
- Configuration management and version control tools

What other tools do you use?

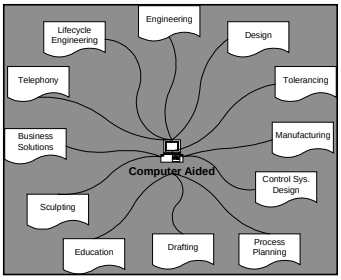
- **GUI builders?**
  - **What kinds, how frequently?**
- **Testing tools?**
  - **What kinds, how frequently?**
- **What else?**

Some historical context

- **Environments and CASE**

CASE

- **Computer Aided Software Engineering**
- **Using computers to help people engineer software**



Environments vs. tools
(very roughly)

- **Integrated**
  - **User interacts with a single environment**
  - **Environment is responsible for managing consistency**
- **Sharing of representation**
- **Standalone**
  - **User interacts with each tool separately**
  - **User must apply tools appropriate to ensure consistency**
- **Independent representations**

Why environments?

- **"During the past decade there has been a growing realization [that software tools] have by and large failed to reduce cost and improve quality. … [T]he essence of an environment is that it attempts to redress the failures of individual software tools through synergistic integration."**
  - **Osterweil, 1981**

Why environments?

- **"Current software development environments often help programmers solve their programming problems by supplying tools such as editors, compilers, and linkers, but rarely do these environments help projects solve their system composition or management problems."**
  - **Notkin & Habermann, 1979**

What are environments?

- **"A software development environment consists of a set of techniques to assist the developers of software systems, supported by some (possibly automated) tools, along with an organizational structure to manage the process of software development. Historically, these facilities have been poorly integrated."**
  - **Wasserman, 1981**

Computer help?

- **Interaction and rich user interfaces**
- **Translation of high-level descriptions**
- **Maintaining consistency among large and complex representations**
- **Encoding knowledge about an activity, organization or process**
- **Broader availability of pertinent information**
- **Communication medium**

The "promise" of CASE

- **Aside**
  - **Parnas's view of artificial intelligence as a "promising" technology**

CASE is ...

- **"The CASE technology is a combination of software tools and methodologies. … Spanning all phases of the software lifecycle, not just on implementation, CASE is the most complete software technology yet."**
  - **McClure, 1989**

CASE is ...

- **"To be truly successful, a CASE product must literally support application development from womb to tomb, from the initial conception of an application through its long-term maintenance."**
  - **Towner, 1989**

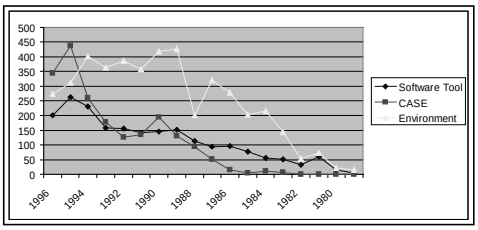
CASE is

- **"CASE provides the rigorous automated support required to build flexible, high-quality information systems quickly."**
  - **Mylls, 1994**

CASE confusion

- Environments in academia, CASE in industry
- CASE in information systems & information technology
  - The MIS world of CIOs
  - Application Development (AD)
  - Information Engineering (IE)
  - Methodology plays a key role
- "Upper" CASE vs. "lower" CASE

Appearances in INSPEC



- Programming *environment*, program development *environment*, software development *environment*, software engineering *environment*, integrated program support *environment*, integrated development *environment*
- 2000 update: environments, 427; CASE, 200; software tools, 465

(A few) classic environments

- Interlisp
- Smalltalk-80
- Unix
- Cedar

Interlisp (Xerox PARC)

- Teitelman & Masinter, 1981
- Language-centered environment
- Very fast turnaround for code changes
- Monolithic address space
  - Environment, tools, application code commingled
- Code and data share common representation

Smalltalk-80 (Xerox PARC)

- Goldberg, 1984
- Language-centered environment (OO)
  - Classes as first-class objects, inheritance, etc.
- Environment structured around language features (class browsers, protocols, etc.)
- Rich libraries (data structures, UI, etc.)

Unix (Bell Labs)

- Toolkit-based environment
- Simple integration mechanism
  - Convenient user-level syntax for composition
- Standard shared representation
- Language-independent (although biased)
- Efficient for systems' programming

Cedar (Xerox PARC)

- Teitelman, 1984
- Intended to mix best features of Interlisp, Smalltalk-80, and Mesa
- Primarily was an improvement on Mesa
  - Language-centered environment
  - Abstract data type language
    - Strong language and environment support for interfaces
  - Key addition: garbage collection

Commercialization

- 22 companies matched "CASE" in Company Profiles database [Spring 1997]
  - About 10,000 matched "software"
  - 23 matched "application development"
- 3 Yahoo CASE categories [Spring 1997]
  - 55-60 registered CASE pages in Yahoo
  - (35 Java categories, thousands of pages)

The business of CASE

- IDE (Software through Pictures)
  - Founded 1983
  - Acquired by Thomson-CSF 1996
    - ~$10M annual sales
- Rational
  - Founded 1982
  - $572M sales in 2000

The business of CASE

- Popkin
  - Founded 1986
    - ~$15M annual sales
- Cayenne Software, Inc. (1996)
  - Merger of Bachman (1983) and CADRE (1982)
    - ~$14M annual sales
    - Now out of business
- StructSoft (TurboCASE/Sys)
  - Formed 1984
    - ~$6M annual sales

The business of CASE

- I-Logix
  - Founded 1987
    - ~$10M annual sales
- Reasoning Systems
  - Founded 1984
    - ~$20M annual sales

Some context

- SAP AG
  - R/3 Business Process (Re)Engineering
  - Founded 1972
    - >$2B annual revenue
- Largest "application development" company in Company Profiles
  - Progress Software, 1981
  - ~$180M annual revenue

CASE quotation I

- **"Despite the many grand predictions of the trade press over the past decade, computer-assisted software engineering (CASE) tools failed to emerge as the promised `silver bullet.'"**
  - **Guinan, Cooprider, Sawyer; IBM Systems Journal, 1997**

CASE quotation II

- **"CASE tools are sometimes excessively rigid in forcing the user to input too much information before giving usable results back. CASE tools also typically don't adapt to multiple or in-house methodologies…"**
  - **www.confluent.com; 1997**

Myth #1 of CASE

- ***Integration is job #1***
- **Integrating tools helps, but only if the tools are the "right" tools**
- **That is, integration is a second order effect, not a first order effect**

Myth #2 of CASE

- ***Graphics inherently dominate text***
  - **"A picture is worth a thousand words"**
- **This is a complicated issue**
  - **Screen real estate**
  - **Sharing with other tools**
  - **Sharing with other people**

Myth #3 of CASE

- ***Software tools are more important than intellectual tools***
- **False**
  - **Software tools are important but are generally a second order effect**
  - **Sometimes software tools can qualitatively change the world, although usually indirectly**

Myth #4 of CASE

- ***Tool adoption is a consumer problem not a producer problem***
- **False**

Organizational issues (Orlikowski)

- **"CASE Tools as Organizational Change: Investigating Incremental and Radical Changes in Systems Development"**
  - **MIS Quarterly Best Paper, 1993**
- **"[To] account for the experiences and outcomes associated with CASE tools, researchers should consider the social context of systems development, the intentions and actions of key players, and the implementation process following by the organization."**

Myth #5 of CASE

- ***Goal should be to change how software engineering is done***
- **No, it should be to enhance how people are doing software engineering**

Myth #6 of CASE

- ***The tools can handle creative aspects of software engineering***
- **Tools frequently fail to be useful because they make poor judgments about what the human does well and what the computer does well**

Tools

- **For at least a while, the pendulum seems to have moved back towards tools rather than environments/CASE**
  - **This isn't uniformly true, but I think it is true on the whole**
- **Undoubtedly, at some point the pendulum will swing back again**

News Flash! Notkin's wrong!

- **From the Miller Freeman, Inc. newswire from November 23, 1998**
- **'Better, faster, cheaper,' the mantra of technology vendors still drives product development and marketing. But now a new word must be added: integrated. This year's Intelligent Enterprise Dozen offers testament to the importance of application integration. Today, vendors find that customers have the parts; now they want the whole. Best-of-breed products must adhere to industry standards; packages must work together; and productivity tools, such as decision support, must become closed-loop solutions.**

Programming languages

- **Many (researchers, especially) claim that with better programming languages, we'd have no need (or significantly reduced need) for software tools**
- **How many of you took CSE583?**
  - **Scheme, ML, Haskell, etc.**
- **Assuming you could/would build most commercial products with such languages, which tools would you give up?**
  - **Probably none**

However

- The underlying premises and implementation structures for many tools and language implementations are closely related
- Examples include:
  - The program dependence graph representation is heavily used in program optimization and parallelization, as well as in software engineering tools
  - Type inference is being used increasingly broadly as the basis for some software engineering tools
    - We'll see one concrete example, Lackwit

Types

- Type systems fit into the definition of analysis we're using
- These systems are intended to eliminate some classes of errors in programs
  - Programs in a language are analyzed and ones that don't pass type checking are considered illegal programs (static typing)
  - During execution checks are made to ensure that bit representations are never misinterpreted (dynamic typing)

Type inferencing

- A downside of type systems is that the programmer has to write more "stuff"
- Type inferencing has the compiler compute what the types of the expressions should be
  - The programmer writes less down
  - The programmer has less to change when the program is modified
  - The programmer gets almost all the benefits of static typing

Static vs. dynamic tools

- Static tools
  - Analyze the source per se
  - Analysis applies to all possible executions
- Dynamic tools
  - Analyze executions of the program and the source together
  - Analysis only applies to those executions

Static tools

- [Remember the information issues in source model extraction]
- Generally return source models with no false negatives (conservative)
- Because of the underlying undecidability of most interesting analyses generally returns imprecise models (includes many false positives)

Dynamic tools

- Generally return source models with no false positives
- May omit many true positives

A classic static tool: slicing

- Of interest by itself
- And for the underlying representations
  - Originally, data flow
  - Later, program dependence graphs

Slicing, dicing, chopping

- Program slicing is an approach to selecting semantically related statements from a program [Weiser]
- In particular, a slice of a program with respect to a program point is a projection of the program that includes only the parts of the program that might affect the values of the variables used at that point
  - The slice consists of a set of statements that are usually not contiguous

Basic ideas

- If you need to perform a software engineering task, selecting a slice will reduce the size of the code base that you need to consider
- Debugging was the first task considered
  - Weiser even performed some basic user studies
- Claims have been made about how slicing might aid program understanding, maintenance, testing, differencing, specialization, reuse and merging

Example

```
read(n)
i := 1;
sum := 0;
product := 1;
while i <= n do begin
    sum := sum + i;
    product :=
      product * i;
    i := i + 1;
end;
write(sum);
write(product);
```

```
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end;
write(sum);
write(product);
```

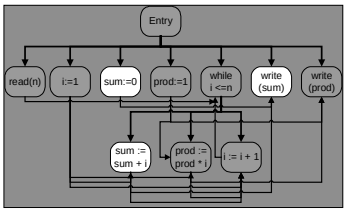
This example (and other material) due in part to Frank Tip

Weiser's approach

- For Weiser, a slice was a reduced, executable program obtained by removing statements from a program
  - The new program had to share parts of the behavior of the original
- Weiser computed slices using a dataflow algorithm, given a program point (criterion)
  - Using data flow and control dependences, iteratively add sets of relevant statements until a fixpoint is reached

Ottenstein & Ottenstein

- Build a program dependence graph (PDG) representing a program
- Select node(s) that identify the slicing criterion
- The slice for that criterion is the reachable nodes in the PDG



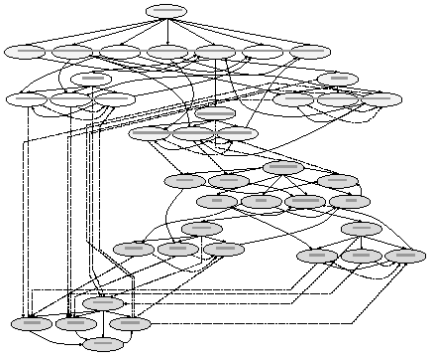
- Thick lines are control dependences
- Thin lines are (data) flow dependences

Procedures

- What happens when you have procedures and still want to slice?
- Weiser extended his dataflow algorithm to interprocedural slicing
- The PDG approach also extends to procedures
  - But interprocedural PDGs are a bit hairy (Horwitz, Reps, Binkley used SDGs)
  - Representing conventional parameter passing is not straightforward

The next slide...

- ..shows a fuzzy version of the SDG for a version of the product/sum program
  - Procedures `Add` and `Multiply` are defined
  - They are invoked to compute the `sum`, the `product` and to increment `i` in the loop



Context

- A big issue in interprocedural slicing is whether context is considered
- In Weiser's algorithm, every call to a procedure could be considered as returning to *any* call site
  - This may significantly increase the size of a slice

Reps et al.

- Reps and colleagues have a number of results for handling contextual information for slices
- These algorithms generally work to respect the call-return structure of the original program
  - This information is usually captured as summary edges for call nodes

Technical issues

- How to slice in the face of unstructured control flow?
- Must slices be executable?
- What about slicing in the face of pointers?
- What about those pesky preprocessor statements?

LCLint next

- Probably shifted until next week, depending on the time

LCLint [Evans et al.]

- [Material taken in part from a talk by S. Garland]
- Add some partial specification information to C code to
  - Detect potential bugs
  - Enforce coding style
- Versatile and lightweight
  - Incremental gain for incremental effort
  - Fits in with other tools

Detects potential bugs

- Specifications enable more accurate checks, messages
- Memory management a particular problem in the C language

Enforces coding style

- Abstraction boundaries
- Use of mutable and immutable types

LCLint Does Not

- Encourage programmer to write
  - Contorted code
  - Inefficient code
- Report only actual errors
- Report all errors
- Insist on reporting a fixed set of potential errors
  - Many options and control flags

Ex: Definition before Use

- Sample code…can annotate in several ways
  - `if (setVal(n, &buffer)) ...`
- Must `buffer` be defined before calling `setVal`?
  - Yes: `bool setVal(int d, char *val);`
  - No: `bool setVal(int d, out char *val);`
- Is `buffer` defined afterwards?
  - Yes: `bool setVal(...); {modifies *val;}`
  - Maybe: `bool setVal(...); {modifies nothing;}`
  - NO!: `bool setVal(...); {ensures trashed(val);}`

More Accurate Checks

- Conventional lint tools report
  - Too many spurious errors
  - Too few actual errors
- Because
  - Code does not reveal the programmer's intent
  - Fast checks require simplifying assumptions
- Specifications give good simplifying assumptions

Abstraction Boundaries

- Client code should rely only on specifications
- Types can be specified as abstract
  - immutable type `date`;
    - `date nextDay(date d); { }`
  - mutable type `set`;
    - `void merge(set s, set t); {modifies s;}`
- LCLint detects
  - Inappropriate access to representation
    - Including use of `==`
  - Inappropriate choice of representation
    - E.g., for meaning of `=` (sharing)

Checking Abstract Types

- Specification: `set.lcl` contains the single line
  - `mutable type set;`
- Client code

```
#include "set.h"
bool f(set s, set t) {
  if (s->size > 0) return (s == t);
  ...
```

- `> lclint set client.c`

```
client.c:4,7:
    Arrow access field of abstract type
          (set): s->size
client.c:5,13:
    Operands of == are abstract
          type (set):  s == t
```

Checking Side Effects

- Specification:

```
void set_insert (set s, int e)
     { modifies s;}
void set_union(set s, set t)
     { modifies s;}
```

- Code (in `set.c`):

```
void set_union (set s, set t) {
    int i;
    for (i = 0; i < s->size; i++)
       set_insert(t, s->elements[i]);
    }
```

- Message:

```
set.c:35, 27:
    Called procedure set_insert may modify t:
       set_insert(t, s->elements[i])
```

Checking Use of Memory

- Specifications

```
only char *gname;
. . .
void setName (temp char *pname) char *gname;
```

- Code

```
void setName (char *pname) {
    gname = pname;
}
```

- LCLint error messages
  - `sample.c:2:3: Only storage gname not released before assignment: gname = pname`
  - `sample.c:2:3: Temp storage assigned to only: gname = pname`

If C Were Better...

- Would LCLint still help?
- Yes, because specifications
  - contain information not in code
  - contain information that is hard to infer from code
  - are usable with legacy code, existing compilers
  - can be written faster than languages can be changed
  - are important even with better languages

Experience with LCLint

- Reliable and efficient
  - Runs at compiler speed
- Used on both new and legacy code
  - 1,000-200,000 line programs
  - Over 500 users have sent e-mail to MIT
- Tested with varying amounts of specification
  - Lots to almost none
  - LCLint approximates missing specifications
- Results encouraging

Understanding Legacy Code

- Analyzed interpreter (quake) built at DEC SRC
- Discovered latent bugs (ordinary lint can do this)
- Discovered programming conventions
  - Documented use of built-in types (int, char, bool)
  - Identified (and repaired) (nearly) abstract types
- Documented action of procedures
  - Use of global information, side-effects
- Enhanced documentation a common thread
  - Easier to read and write because formulaic
  - More trustworthy because checked

Fundamental benefit

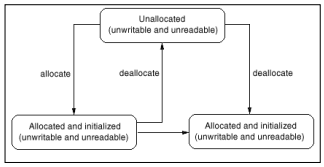
- Partial specifications
- Low entry cost
- You get what you pay for (or maybe a bit more)

Purify (& Bounds-checker)

- Dynamic (commercial) tool for detecting memory leaks and access errors
  - `http://www.rational.com/products/purify/`
  - In some sense, a dynamic analog to the memory checking aspects of LCLint
- Trapping every memory access would be overly expensive
  - Purify inserts function calls before loads and stores to maintain a table that holds a 2-bit state for each byte in the heap and stack
    - Requires working with malloc/free, too

Memory State Transitions

- Writing to memory with any bytes that are unwriteable prints a diagnostic
- Same with reading unreadable bytes



Other violations

- Array Bound Violations
  - Allocate a "red-zone" around malloc blocks, recording them as unwriteable and unreadable
- Uninitialized variables
  - Initialize them to allocated-but-uninitialized state
- Accessing freed memory
  - Do not reallocate memory until it has aged
    - Aging can be specified by the user in terms of number of calls to free

Overhead

- 2 bits per state; about 25% memory overhead during development
- Run-time no worse than 5.5 times optimized C code (and usually no worse than compiling with debugging on)

Next week

- Example tools
  - Type inference (Lackwit)
  - Dynamic invariant detection (Daikon)
  - ...