CSE584: Software Engineering

Lecture 7: Evolution (B)

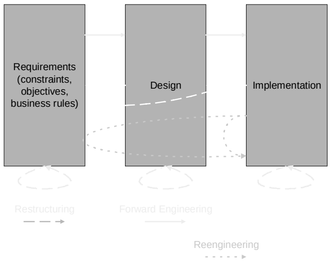
David Notkin
Computer Science & Engineering
University of Washington
http://www.cs.washington.edu/education/courses/584/

Outline

- Reverse engineering
- Visualization
- Software summarization

Miscellaneous visualization, etc.

Chikofsky & Cross taxonomy



Taxonomy

- Design recovery is a subset of reverse engineering
- The objective of design recovery is to discover designs latent in the software
  - These may not be the original designs, even if there were any explicit ones
  - They are generally recovered independent of the task faced by the developer
- It's a way harder problem than design itself

Restructuring

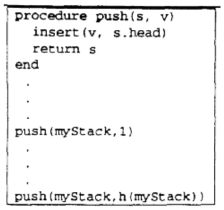
- One taxonomy activity is restructuring
- Last week we noted lots of reasons why people don't restructure in practice
  - Doesn't make money now
  - Introduces new bugs
  - Decreases understanding
  - Political pressures
  - Who wants to do it?
  - Hard to predict lifetime costs & benefits

Griswold's 1st approach

- Griswold developed an approach to meaning-preserving restructuring (as I said last week)
- 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

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

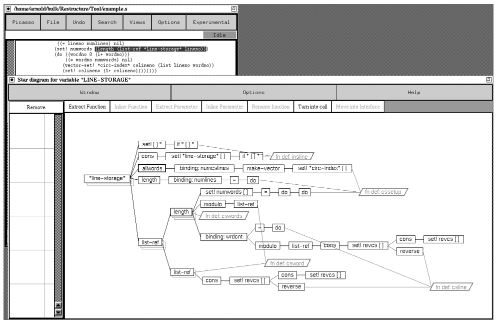
Limited power

- 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
  - We're looking at a support tool now to identify candidate refactorings

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

A star diagram

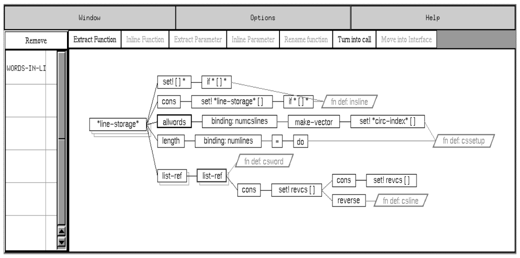


```
            ((= lineno numlines) nil)
           (set! numwords (length (list-ref *line-storage* lineno)))
           (do ((wordno 0 (1+ wordno)))
               ((= wordno numwords) nil)
             (vector-set! *circ-index* cslineno (list lineno wordno))
             (set! cslineno (1+ cslineno))))))))
```

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

After some changes



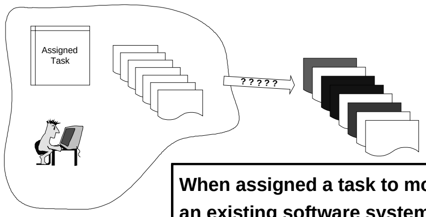
Evaluation

- 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 standard tools adopted more complicated strategies for handling completeness and consistency

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

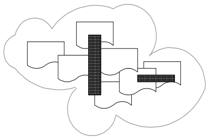
A view of maintenance



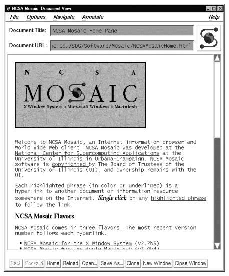
When assigned a task to modify an existing software system, how does a software engineer choose to proceed?

A 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



Mosaic



Document Title: NCSA Mosaic Home Page

Document URL: ıc.edu/SDG/Software/Mosaic/NCSAMosaicHome.html

Welcome to NCSA Mosaic, an Internet information browser and World Wide Web client. NCSA Mosaic was developed at the National Center for Supercomputing Applications at the University of Illinois in Urbana-Champaign. NCSA Mosaic software is copyrighted by The Board of Trustees of the University of Illinois (UI), and ownership remains with the UI.

Each highlighted phrase (in color or underlined) is a hyperlink to another document or information resource somewhere on the Internet. *Single click* on any highlighted phrase to follow the link.

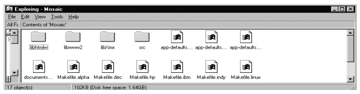
NCSA Mosaic Flavors

NCSA Mosaic comes in three flavors. The most recent version number follows each hyperlink.

- NCSA Mosaic for the X Window System (v2.7b5)
- NCSA Mosaic for the Apple Macintosh (v3.0b4)

- 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)

How to proceed?

- What source model would be useful?
  - calls between functions (particularly calls to Unix TCP/IP library)
- How do we get this source model?
  - *statically* with a tool that analyzes the source or *dynamically* using a profiling tool
  - these differ in information characterization produced (last week's lecture)
    - False positives, false negatives, etc.

More...

- What we have
  - approximate call and global variable reference information
- What we want
  - increase confidence in source model
- Action:
  - collect dynamic call information to augment source model

Augment with dynamic calls

- Compile Mosaic with profiling support
- Run with a variety of test paths and collect profile information
- Extract call graph source model from profiler output
  - 1872 calls
  - 25% overlap with CIA
  - 49% of calls reported by gprof not reported by CIA

Alternative action

- Alternatively, we may have wanted to augment with calls information extracted using a lexical technique
- For example, lexical source model extraction tool (LSME Murphy/Notkin):

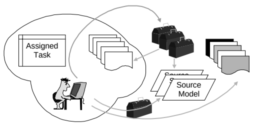
```
[ <type> ] <fn> \( [ { <arg> }+ ] \)
   [ { { <ty> }+ ; }+ ] \{

       <cf> \( [ { <arg> [ , ] }+ ] \)
```

Are we done?

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

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

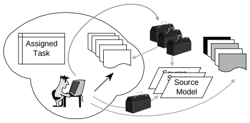
One approach



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

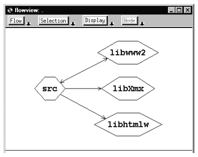
Other approaches

- Visualization
- Reverse engineering
- Summarization

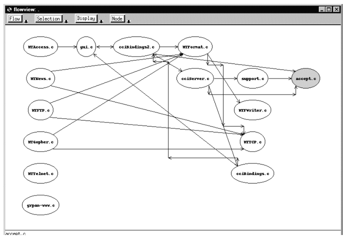


Visualization

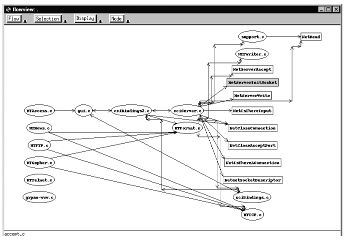
- e.g., Field, Plum, Imagix 4D, McCabe, etc.
(Field's flowview is used above and on the
next few slides...)
- Note: several of these are commercial products



Visualization...



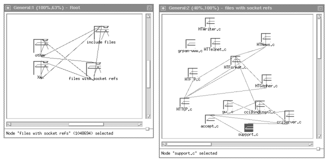
Visualization...



Visualization...

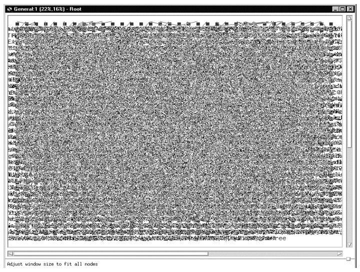
- Provides a "direct" view of the source model
- View often contains too much information
  - Use elision (…)
  - With elision you describe what you are not interested in, as opposed to what you are interested in

Reverse engineering


include files
files with socket refs
Node "files with socket refs" selected
Node "support.c" selected

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

Reverse engineering...


General:1 (223,163) - Root
Adjust window size to fit all nodes

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

Rigi's approach

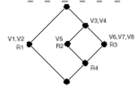
- Extract source models (they call them resource relations)
- Build edge-weighted resource flow graphs
  - Discrete sets on the edges, representing the resources that flow from source to sink
- Compose these to represent subsystems
  - Looking for strong cohesion, weak coupling
- The papers define interconnection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

Math. concept analysis

- Define relationships between (for instance) functions and global variables [Snelting et al.]
- Compute a concept lattice capturing the structure
  - "Clean" lattices = nice structure
  - "ugly" ones = bad structure

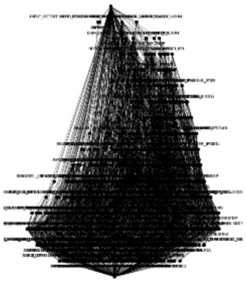
```
SUBROUTINE R1(...)
COMMON /C1/ V1,V2
...
END

SUBROUTINE R2(...)
COMMON /C2/ V3,V4
COMMON /C3/ V5
...
END

SUBROUTINE R3(...)
COMMON /C2/ V3,V4
COMMON /C4/ V6,V7,V8
...
END

SUBROUTINE R4(...)
COMMON /C2/ V3,V4
COMMON /C3/ V3
COMMON /C4/ V6,V7,V8
...
END
```

	V1	V2	V3	V4	V5	V6	V7	V8
R1	–	–						
R2			–	–	–			
R3			–	–		–	–	–
R4			–	–	–	–	–	–



An aerodynamics program

- 106KLOC Fortran
- 20 years old
- 317 subroutines
- 492 global variables
- 46 COMMON blocks

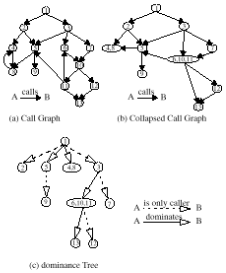


Other concept lattice uses

- File and version dependences across C programs (using the preprocessor)
- Reorganizing class libraries
- Not yet clear how well these work in practice on large systems

Dominator clustering

- Girard & Koschke
- Based on call graphs
- Collapses using a domination relationship
- Heuristics for putting variables into clusters



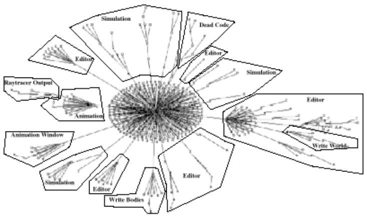
(a) Call Graph

(b) Collapsed Call Graph

(c) dominance Tree

Aero program

- Rigid body simulation; 31KLOC of C code; 36 files; 57 user-defined types; 480 global variables; 488 user-defined routines



Other clustering

- Schwanke
  - Clustering with automatic tuning of thresholds
  - Data and/or control oriented
  - Evaluated on reasonable sized programs
- Basili and Hutchens
  - Data oriented
  - Evaluated on smallish programs

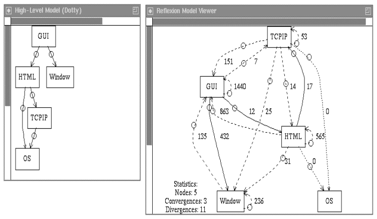
Reverse engineering recap

- Generally produces a higher-level view that is consistent with source
  - Like visualization, can produce a “precise” view
  - Although this might be a precise view of an approximate source model
- Sometimes view still contains too much information leading again to the use of techniques like elision
  - May end up with “optimistic” view

More recap

- Automatic clustering approaches must try to produce “the” design
  - One design fits all
- User-driven clustering may get a good result
  - May take significant work (which may be unavoidable)
  - Replaying this effort may be hard
- Tunable clustering approaches may be hard to tune; unclear how well automatic tuning works

Summarization



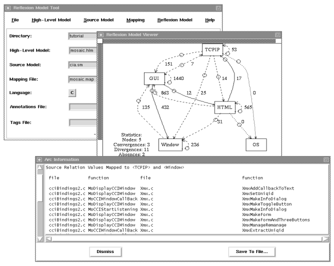
e.g., software reflexion models

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 ]
```

Summarization...



Directory: tutorial

High-Level Model: mosaic.hlm

Source Model: cia.sm

Mapping File: mosaic.map

Language: C

Annotations File:

Tags File:

Statistics:
Nodes: 5
Convergences: 3
Divergences: 11
Absences: 2

```
Source Relation Values Mapped to <TCPIP> and <Window>

 file            function             file                                      function

 cciBindings2.c MoDisplayCCIWindow   Xmx.c                                     XmxAddCallbackToText
 cciBindings2.c MoDisplayCCIWindow   Xmx.c                                     XmxSetUniqid
 cciBindings2.c MoCCIWindowCallBack  Xmx.c                                     XmxMakeInfoDialog
 cciBindings2.c MoDisplayCCIWindow   Xmx.c                                     XmxMakeToggleButton
 cciBindings2.c MoCCIStartListening  Xmx.c                                     XmxMakeInfoDialog
 cciBindings2.c MoDisplayCCIWindow   Xmx.c                                     XmxMakeForm
 cciBindings2.c MoDisplayCCIWindow   Xmx.c                                     XmxMakeFormAndThreeButtons
 cciBindings2.c MoDisplayCCIWindow   Xmx.c                                     XmxManageRemanage
 cciBindings2.c MoCCIWindowCallBack  Xmx.c                                     XmxExtractUniqid
```

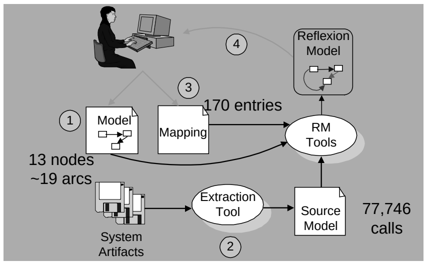
Summarization...

- 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

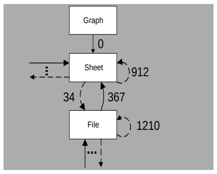
- A series of approximate tools were used by a Microsoft engineer to perform an experimental reengineering task on Excel
- The task involved the identification and extraction of components from Excel
- Excel (then) comprised about 1.2 million lines of C source
  - About 15,000 functions spread over ~400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

The process used

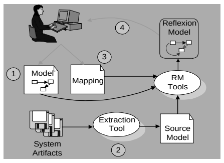


An initial Reflexion Model

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

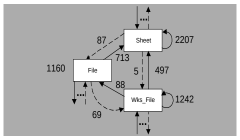


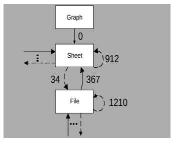
An iterative process



- 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

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

Open questions

- How stable is the mapping as the source code changes?
- Should reflexion models allow comparisons separated by the type of the source model entries?
- ...

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

Miscellaneous

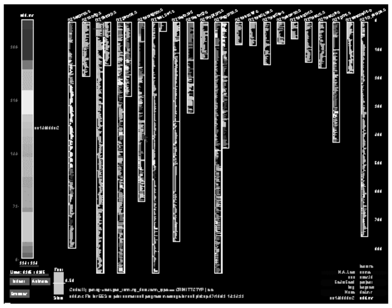
- SeeSoft
- Automatic module clustering (Mancoridis et al.)

SeeSoft: Eick et al.

- Visualize text files by
  - mapping each line into a thin row
  - colored according to a statistic of interest
- Focus on source code, with sample statistics including
  - age, programmer, or functionality of each line
  - Data extracted from version control systems, static analysis and profiling
- User can manipulate this representation to find interesting patterns in software
- Applications include data discovery, project management, code tuning and analysis of development methodologies

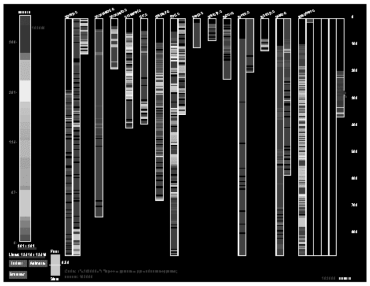
Code age:

newest code in red, oldest in blue



Execution profile:

red shows hot spots, non-executed lines are gray/black



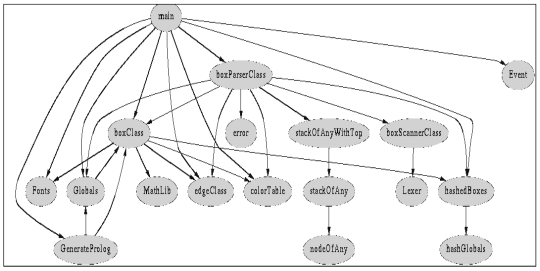
SeeSoft

- SeeSoft seems excellent for building important, qualitative understanding of some aspects of source code
- It also links in effectively with the underlying source code
- It is flexible in terms of what statistics are viewed
  - It's not entirely clear how much work is needed to add a new statistic

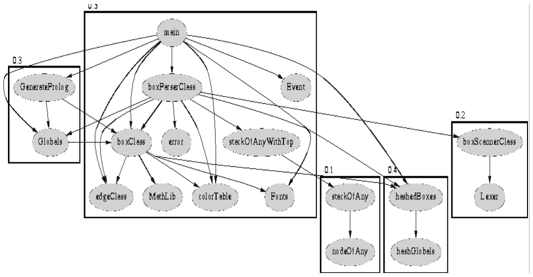
Clustering for Automatic High-Level Design Extractino

- Recover high-level structure
- Roughly, a more automated approach to do some Rigi activities
- Treat clustering as an optimization problem

Module Dependence Graph of a graphical editor



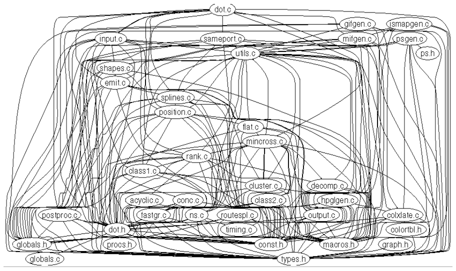
Automatically clustered module dependence graph



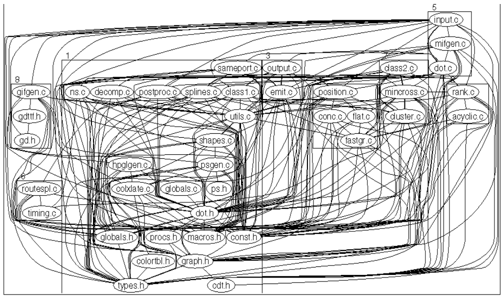
Omnipresent Modules

- **They can account for omnipresent modules**
  - **Those used very broadly or those that use many other modules**
  - **These tend to reduce the quality of the standard clustering approaches**

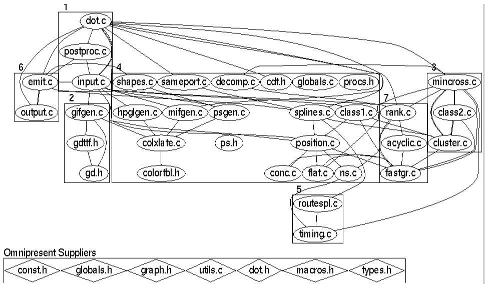
Module diagram for dot



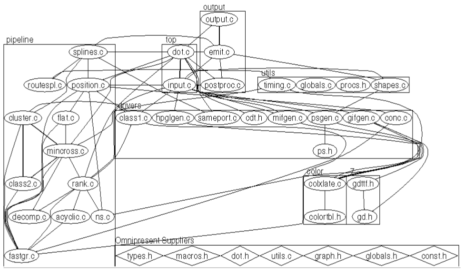
Automatic clustering for dot



With omnipresent module support



All allows user-defined modules



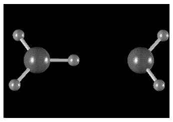
Algorithm Animation:

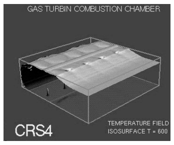
heapsort from Compaq SRC (Brown and Najork)

- Tons of work
- Mostly for educational environments
- Have aided in some research results
- Definitely algorithm oriented
  - Not at the system level

Many domain specific animations:

http://www.crs4.it/Animate/





Summary

- **[Back to evolution]**
- **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**

Why is there a lack of tools to support evolution?

- **Intellectual tools**
- **Actual tools**
- **Opportunities?**