25- Static & Dynamic Analysis

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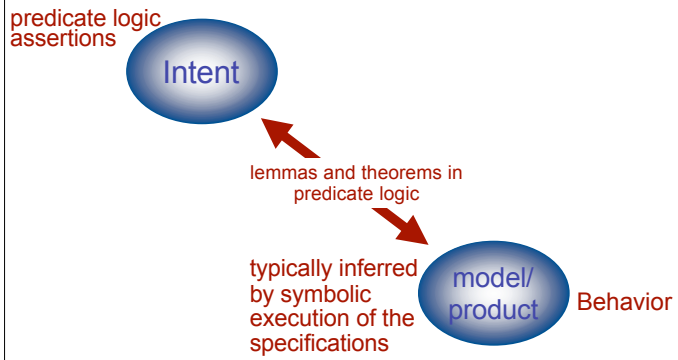
Approaches

- Static Analysis
  - Inspections
  - Software metrics
  - Symbolic execution
  - Dependence Analysis
  - Data flow analysis
  - Software Verification
- Dynamic Analysis
  - Assertions
  - Error seeding, mutation testing
  - Coverage criteria
  - Fault-based testing
  - Specification-based testing
  - Object-oriented testing
  - Regression testing

Verification

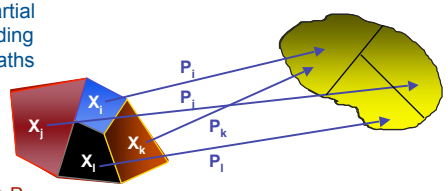
- How are they different?
  - (Automated) mathematical reasoning
    - difficult, error prone
    - decidability vs. expressiveness
      - Propositional calculus is decidable
      - Predicate calculus is semi-decidable
  - Finite-state verification
    - Reason about a finite model of the system
    - Fast, yields counterexamples, manages partial specifications, applies to concurrency
    - State explosion!

Proof



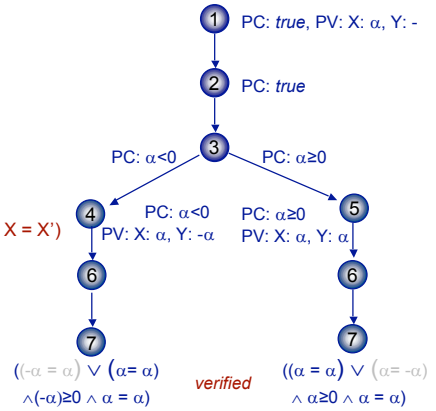
Symbolic Evaluation/Execution

- Creates a functional representation of a path of an executable component
- P is composed of partial functions corresponding to the executable paths
  $P = \{P_1,...,P_r\}$
  $P_i : X_i \rightarrow Y$
- For a path P_i
  - $D[P_i]$ is the domain for path P_i
  - $C[P_i]$ is the computation for path P_i



Execution tree (Hantler-King)

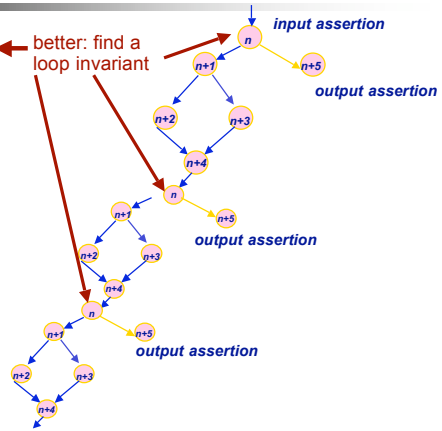
```
ABSOLUTE
assume (true)
1   procedure(X);
2   declare X,Y integer
3   if X<0
4       then Y← -X;
5       else Y← X;
6   return (Y);
prove((Y = X'|Y = -X') & Y≥0 & X = X')
7   end;
```



Loops -- unroll them?

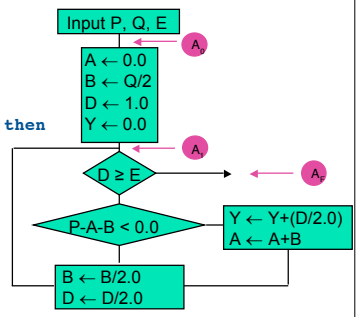
```
                 input asssertion
n                  do_while predicate1
n+1                  if predicate2
n+2                    then code ;
n+3                    else code ;
n+4                end;
n+5              output assertion ;
```

better: find a loop invariant



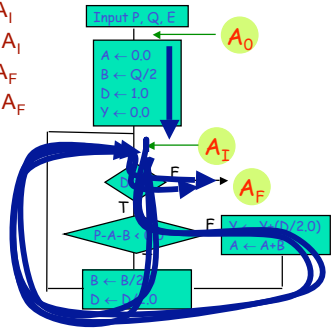
Floyd Proof: Wensley's Algorithm

```
Procedure Wensley (P:input, Q:input, E:input, Y:output);
Declare P, Q, E, Y, A, B, D real;
A := 0.0;
B := Q/2.0;
D := 1.0;
Y := 0.0;
Do_While (D>=E)
   If ~(P - A - B ≥ 0.0) then
       { Y := Y+(D/2.0);
         A := A+B};
   B := B/2.0;
   D := D/2.0;
   End_do;
End Wensley;
```



Floyd Proof: Wensley's Algorithm

- Summary of Five Lemmas Needed
  - A_0 to A_I
  - A_I, true branch, to A_I
  - A_I, false branch, to A_I
  - A_I, true branch, to A_F
  - A_I, false branch, to A_F



Hoare axiomatic proof

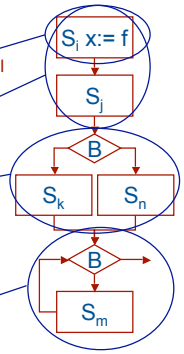
- assertions are preconditions and post conditions on some statement or sequence of statements

  P{S}Q
- if P is true before S is executed and S is executed then Q is true
- as in Floyd's inductive assertion method, we construct a sequence of assertions, each of which can be inferred from previously proved assertions and the rules and axioms about the statements and operations of the program
- to prove P{S}Q, we need some axioms and rules about the programming language

Hoare axioms and proof rules

- axiom of assignment
  - P {x:=f} Q,
  - where Q is obtained from P by substituting f for all occurrences of x in P (symbolic execution)
- rule of composition
  - P {S1, S2 } Q => ∃ P1 , P{S1}P1 ∧ P1{S2}Q
- rule for the alternative statement
  - P{if B then S1 else S2 }Q ⇒ P{B ∧ S1}Q ∧ P{¬B ∧ S2}Q
- rules of consequence
  - [P {S} Q ∧ Q ⇒ R] ⇒ P {S} R
  - [P {S} Q ∧ R ⇒ P] ⇒ R {S} Q
- rule of iteration
  - P {while B do S }Q ⇒ P{~B}Q ∧(∃ I) ∧ P {B ∧ S} I ∧ I{B ∧ S } I ∧ I{~B }Q

loop invariant



backwards substitution

Proof

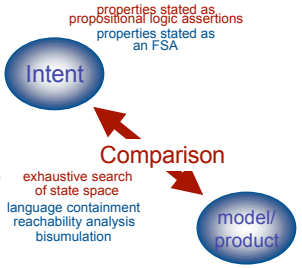
- Hoare-style and Floyd- style verification are essentially the same
  - one is based on graphical representation and the other on a textual representation.
    - In Floyd-style proof, we visualize the proof goal by annotating a CFG
    - In the other, we define the proof goal as a Hoare triple
- Mechanism for applying proof
  - may work either direction on such a proof, but because it's typically easier to work backwards, often use a technique called backwards substitution
  - we work our way from the post-condition, using the proof rules to "push formulas through" the program
  - at each point where a "pushed-through" predicate "runs into" a supplied predicate, we have a verification condition (VC) that must be proved.
  - After all VCs are proved, we need to be prove termination
    - Without a termination proof, we achieve **partial correctness**
    - With a termination proof, we achieve **total correctness**

Straightforward Observations

- Problems
  - formal proofs are long, tedious and are often hard; assertions are hard to get right; invariants are difficult to get right (need to be invariant, but also need to support overall proof strategy)
- Unsuccessful proof attempt ⇒ ???
  - incorrect software? assertions? placement of assertion? inept prover? although failed proofs often indicate which of the above is likely to be true (especially to an astute prover)
- Deeper Issues
  - undecidability of predicate calculus ⇒ no way to be sure when you have a false theorem
  - there is no sure way to know when you should quit trying to prove a theorem (and change something)
  - proofs are generally much longer than the software being verified ⇒ errors in the proof are more likely than errors in the software being verified

Model Checking: Overview

- properties usually expressed in
  - in a propositional logic (e.g., temporal logic)
  - as a FSA
- system represented as a (possibly "abstracted") reachability graph
- reasoning engine
  - logic ⇒ propagates valid sub-formulas through the graph
  - FSA ⇒ compares FSAs via language inclusion; reachability; or bisumulation



Conservative Analysis

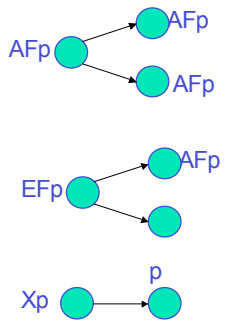
- If property is verified, property holds for all possible executions of the system
- If property is not verified:
  - an error found
    OR
  - a spurious result
- System model abstracts information to be tractable
  - Conservative abstractions usually over-approximate behavior
  - If inconsistency relies upon over-approximations, then a spurious result
  - e.g. all counter example correspond to infeasible paths

Temporal logic

- augments the standard operators of propositional logic with "tense" operators
- "possible worlds semantics" ⇒ Kripke model
  - relativize the truth of a statement to temporal stages or states
  - a statement is not simply true, but true at a particular state
  - states are temporally ordered, with the type of temporal order determined by the choice of axioms.
- model of time
  - partially ordered time
  - linearly ordered time
    - linear temporal logic is typically extended by two additional operators, "until" and "since"
  - discrete time
  - branching (nondeterministic) time
    - foundation for one of the principal approaches to verifying concurrent systems = Computational Tree Logics.

Computation Tree Logics

- specification language
  - a propositional temporal logic.
- verification procedure
  - exhaustive search of the state space of the concurrent system to determine truth of specification.
- formulas constructed from path quantifiers and temporal operators:
  - path quantifier:
    - A "for every path"
    - E "there exists a path"
  - temporal operator:
    - Xp "p holds next time'
    - Fp "p holds sometime in the future"
    - Gp "p holds globally in the future"
    - pUq "p holds until q holds"

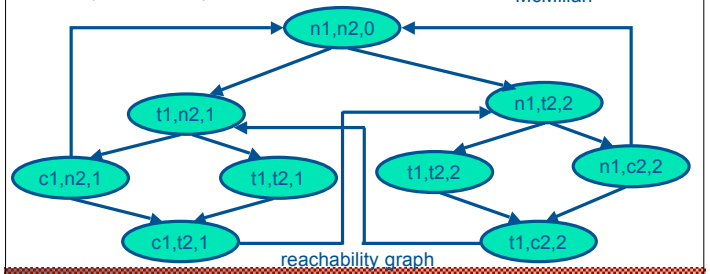


mutual exclusion protocol

- Example: processes can be null, trying to obtain the lock, or in a critical region (n1, t1, c1) or (n2, t2, c2)
  - TURN is a variable that indicates which process can obtain the lock (0,1,2)
- Need a reachability graph that shows that states (i.e., the values) of the variables

process1 = n1,t1,c1
process2 = n2,t2,c2
turn = 0,1,2

*McMillan

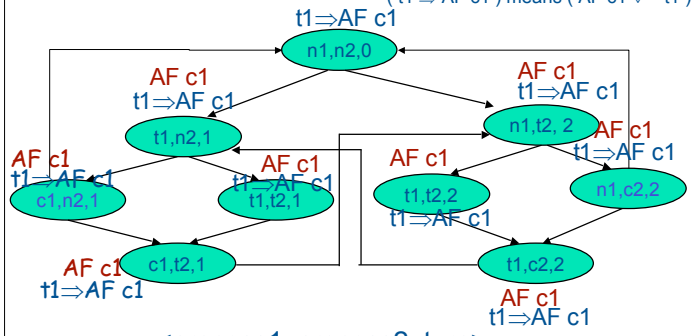


reachability graph

Example: propagation

AG(t1⇒AF c1)

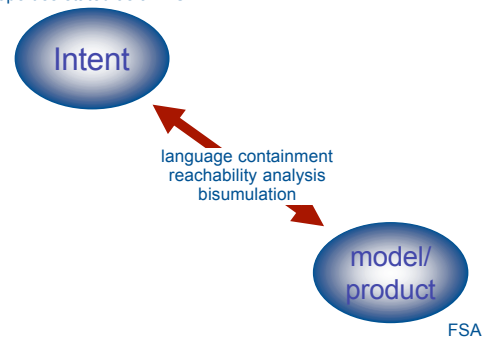
- a ⇒b means (b or ¬ a)
- (t1 ⇒ AF c1) means (AF c1 ∨ ¬ t1)



<process1, process2, turn>

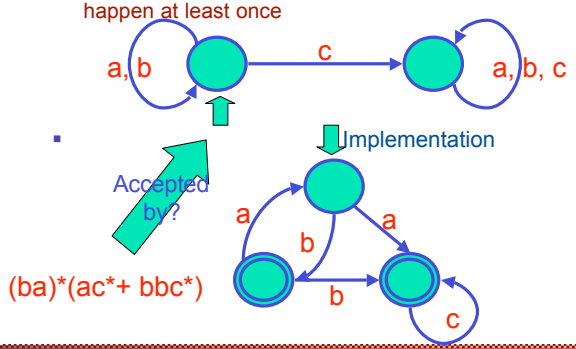
Automata-Theoretic Model Checking

properties stated as an FSA



Example

- Specification:
  - of the possible observable events (a, b, c), c must happen at least once



Some observations

- Model Checking
  - worst case bound linear in size of the model
    - but the model is exponential
  - not clear if model checking or symbolic model checking is superior
    - depends on the problem
  - experimentally often very effective!
    - used selectively to verify hardware designs
    - trying to develop appropriate abstractions to make it applicable to software systems

Approaches

- Static Analysis
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  - Software metrics
  - Symbolic execution
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  - Error seeding, mutation testing
  - Coverage criteria
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  - Object-oriented testing
  - Regression testing

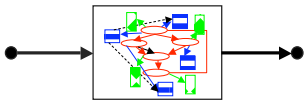
Types of Testing--what is tested

- Unit testing
  - exercise a single simple (procedure) component
- Integration testing
  - exercise a collection of inter-dependent components
  - focus on interfaces between components
- System testing
  - exercise a complete, stand-alone system
- Acceptance testing
  - customer's evaluation of a system
  - usually a form of system testing
- Regression testing
  - exercise a changed system
  - Focus on modifications or their impact

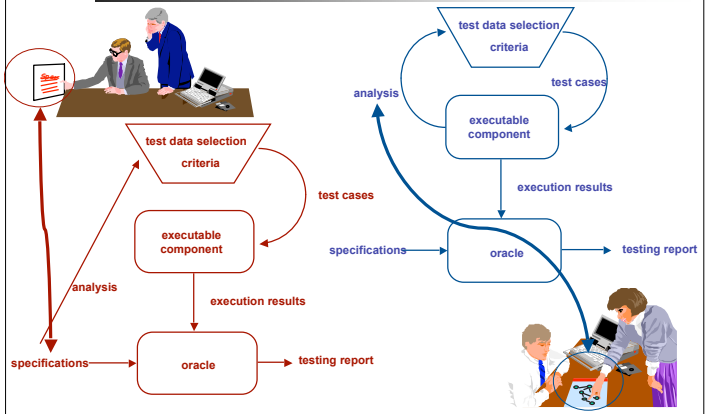
Testing approaches

- "black box"

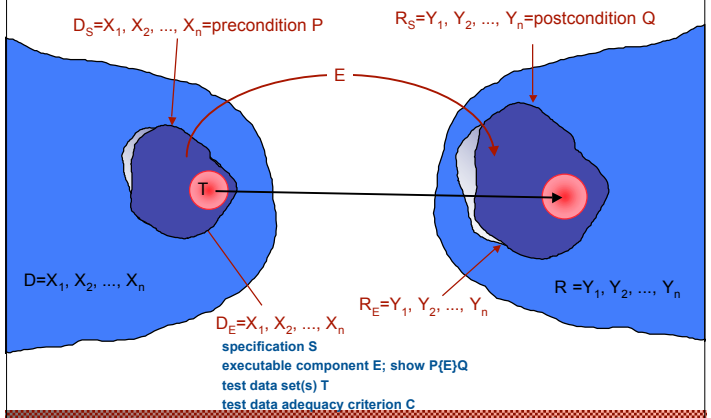
- "white box" or "glass box"



White & Black box testing processes



Testing Theory



Testing Theory

- Criterion C for Test Adequacy
  - C:SxE ->2^T

▪specification-based	C (s)	"black box"
▪interface-based	C (x1, x2, ..., xn, y1, y2, ..., yn)	
▪program-based	C (e)	
▪combined	C (s,e)	"white box"

- Types
  - ▪structural
  - ▪fault-based
  - ▪error-based
  - ▪if specification S defines a function F, such that P{F}Q, then C is *reliable* if $T_1, T_2, ..., T_m$; $C(T_i, E)$; and $D(E) \supseteq T_i$
    - ▪$\forall T_i (\forall t \in T_i, E(t) = F(t)) \vee \forall T_i (\exists t \in T_i \; E(t) \neq F(t))$
    - ▪$\forall t \in T_i, E(t) = F(t) \Rightarrow \forall t \in T_i \; OK(T_i) \Rightarrow E \equiv F$

Ideal Test Criterion

- test criterion C is *ideal* if for any executable component E and every test set $T_i \subseteq D(E)$ such that $C(T_i, E)$, T_i is successful
  - of course we want $T_i << D(E)$
  - but in general, T= D(P) is the only ideal test criterion
- In general, there is no ideal test criterion
  "Testing shows the presence, not the absence of bugs"
  E. Dijkstra
- Dijkstra was arguing that verification was better than testing
- but, verification has similar problems
  - can't prove an arbitrary program is correct
    - can't solve the halting problem
  - can't determine if the specification is complete
- need to use these techniques so that they compliment one another

Black Box Testing

- Functional/Interface Test Data Selection
  - typical cases
  - boundary conditions/values
  - illegal conditions (if robust)
  - fault-revealing cases
    - based on intuition about what is likely to break the system
  - other special cases
- stress testing
  - large amounts of data
  - worse case operating conditions
- combinations of events
  - select those cases that appear to be more error-prone
- common representations for selecting sequences of events
  - decision tables
  - cause and effect graphs
  - usage scenarios

"White Box" Test Data Selection

- structural
  - coverage based
- fault-based
  - e.g., mutation testing, RELAY
- error-based
  - domain and computation based
  - use representations created by symbolic execution

CFG-Based Coverage

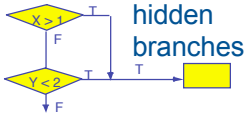
- Criteria
  - Statement Coverage
  - Path Coverage
  - Cyclomatic-number
  - Branch Coverage
  - Hidden Paths
  - Loop Guidelines
  - Boundary - Interior
- Selecting paths that satisfy the criteria
  - static selection
    - some of the associated paths may be infeasible
  - dynamic selection
    - monitors coverage and displays areas that have not been satisfactorily covered

"Simple" coverage measures

- Statement Coverage
  - requires that each statement in a program be executed at least once
    - a set P of paths in the CFP satisfies the statement coverage criterion iff $\forall n_i \in N, \quad \exists p \in P$ such that n_i is on path p
- Path Coverage
  - Requires that every path in the program be executed at least once
    - P satisfies the path coverage criterion iff P contains all execution paths from the start node to the end node in the CFG
  - In most programs, path coverage is impossible
- Multiple Condition Coverage
  - T is adequate if for every condition C which consists of atomic predicates $(p_1, p_2, ..., p_n)$ and all possible combinations $(b_1, b_2, ..., b_n)$ of their values, there is at least one $t \in T$ such that the value of p_i is equal to b_i for all i

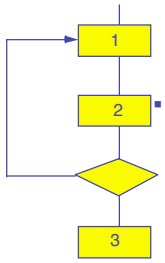
Branch & Loop Coverage

- Branch Coverage
  - Requires that each branch in a program (each edge in a control flow graph) be executed at least once
    - e.g., Each predicate must evaluate to each of its possible outcomes
  - Branch coverage is stronger than statement coverage



hidden branches

- Loop Coverage
  - Path 1, 2, 1, 2, 3 executes all branches (and all statements) but does not execute the loop well.
- Better
  - fall through case
  - minimum number of iterations
  - minimum +1 number of iterations
  - maximum number of iterations
  - maximum -1 number of iterations



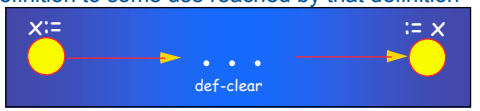
1, 2, 1, 2, 1, 2, 3
$(1, 2)^{n-1}$, 3
$(1, 2)^{n}$, 3

Data Flow Path Selection

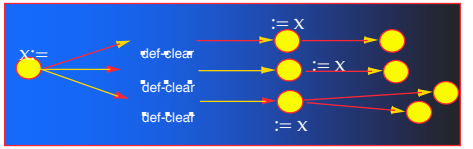
- Definitions
  - $d_n(x)$ denotes that variable x is assigned a value at node n (defined)
  - $u_m(y)$ denotes that variable y is used (referenced at node m)
    - a definition clear path p with respect to (wrt) x is a subpath where x is not defined at any of the nodes in p
    - a definition $d_m(x)$ reaches a use $u_n(x)$ iff there is a subpath (m) p (n) such that p is definition clear wrt x
- Rapps and Weyuker
  - definition-clear subpaths from definitions to uses
- Ntafos
  - chains of alternating definitions and uses linked by definition-clear subpaths
- Laski and Korel
  - combinations of definitions that reach uses at a node via a subpath

Rapps' and Weyuker's DF Criteria

- All-Defs - Some definition-clear subpath from each definition to some use reached by that definition

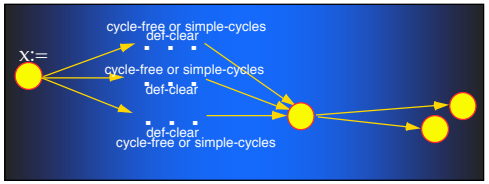


- All-Uses- Some definition-clear subpath from each definition to each use reached by that definition and each successor node of the use



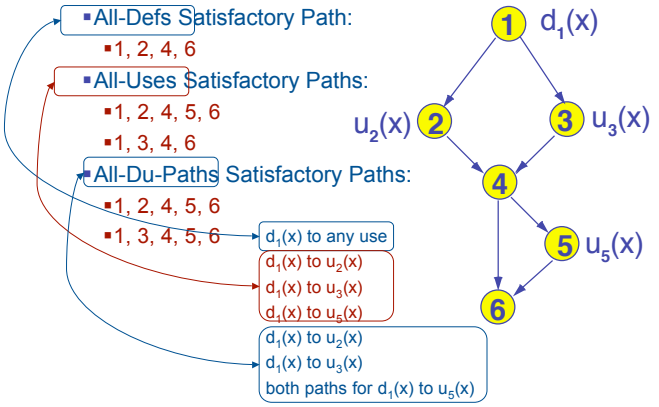
Rapps' and Weyuker's DF Criteria

- All-C-Uses, Some-P-Uses C-use is a "computation use" P-use is a "predicate use"
  - either All-C-Uses for dm(x) or at least one P-Use
- All-P-Uses, Some-C-Uses
  - either All-P-Uses for dm(x) or at least one C-Use
- All-Du-Paths
  - All definition-clear subpaths that are cycle-free or simple-cycles from each definition to each use reached by that definition and each successor node of the use



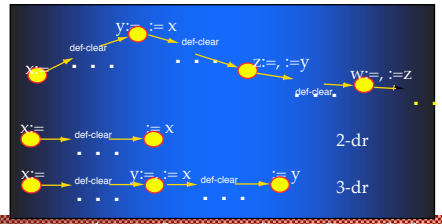
Examples

- All-Defs Satisfactory Path:
  - 1, 2, 4, 6
- All-Uses Satisfactory Paths:
  - 1, 2, 4, 5, 6
  - 1, 3, 4, 6
- All-Du-Paths Satisfactory Paths:
  - 1, 2, 4, 5, 6
  - 1, 3, 4, 5, 6



Ntafos k-dr Data Flow Criteria

- Chains of alternating definitions and uses linked by definition-clear subpaths (k-dr interactions)
  - ith definition reaches ith use,
  - which defines (i+1)st definition
- Required K-tuples
  - Some subpath propagating each k-dr interaction
    - + if last use is a predicate, both branches
    - + if first definition or last use is in a loop, minimal and some larger number of loop iterations

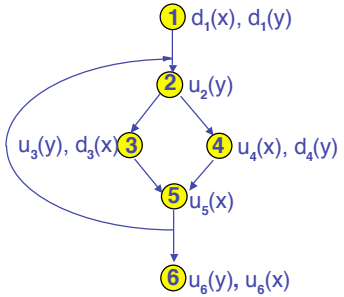


3-DR interactions

d1(x), u4(x), d4(y), u6(y)
d1(x), u4(x), d4(y), u2(y)
d1(x), u4(x), d4(y), u3(y)
d1(y), u3(y), d3(x), u5(x)
d1(y), u3(y), d3(x), u6(x)
d1(y), u3(y), d3(x), u4(x)
d3(x), u4(x), d4(y), u6(y)
d4(y), u3(y), d3(x), u5(x)
d4(y), u3(y), d3(x), u6(x)

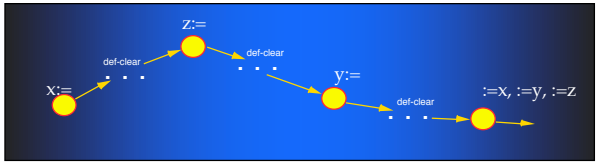
Paths

- 2-DR paths

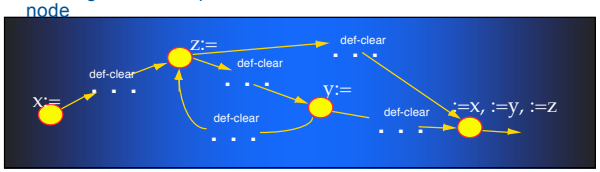


Laski's and Korel's Criteria

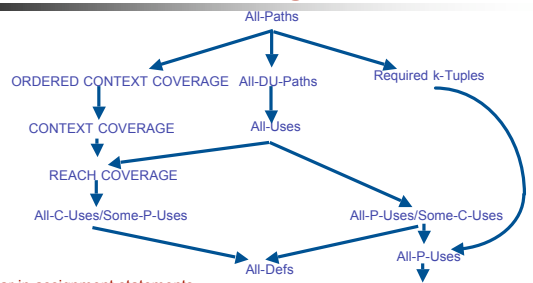
- Context Coverage - Some subpath along which each set of definitions reach uses at some node



- Ordered Context Coverage -Some subpath along which each ordering of each sequence of definitions reach uses at some node



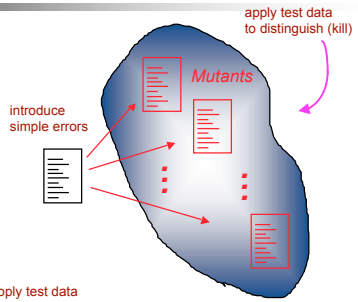
Relationships among criteria



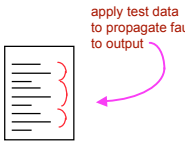
- All-Defs -- linear in assignment statements
- All-Uses -- quadratic in assignment statements
- All-DU-paths -- exponential in assignment statements, but empirically, all are linear in conditional statements
- Required 2-tuples -- quadratic in statements
- Reach -- linear in definitions that reach uses
- Context -- quadratic in definitions that reach uses

Fault-based Techniques

- Mutation Testing



- Fault propagation



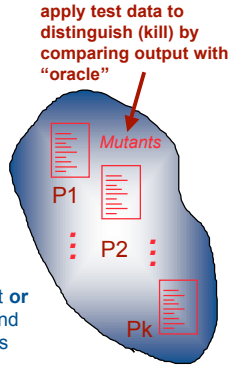
Mutation Testing

- Competent Programmer Hypothesis
  - programmers write programs that are reasonably close to the desired program
    - e.g., sort program is not written as a hash table
- Coupling Effect
  - detecting simple atomic faults will lead to the detection of more complex faults
- considers all simple (atomic) faults that could occur
  - introduces single faults one at a time to create "mutants" of original program
  - interactively(?) apply test data to complete (or partial) set of mutants
  - "test adequacy" is measured by "mutants killed"

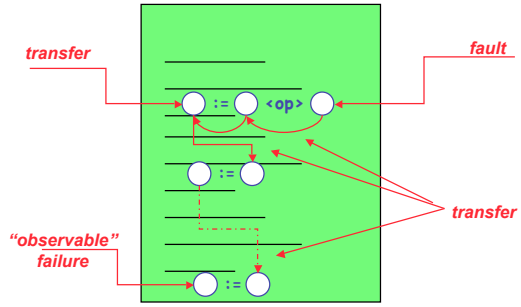
operand mutations:
A : = X + 1; ⇒ A : = X + 2 or ⇒ A : = X + Y
binary operator replacement:
A : = X + 1; ⇒ A : = X - 1 or ⇒ A : = X * 1
statement replacement:
A : = X + 1; ⇒ continue or ⇒ return

Mutation testing process

- Execute program P on test set T
  - save results R to serve as an oracle
  - P is considered the "correct" program
- Each fault results in a new program
  - Mutant programs = P1,...,Pk
- Execute each mutant Pi on T and compare results Ri to R
  - If Ri ≠ R then mutant is killed
  - if Ri = R then either
    - Pi = P, thus it is an **equivalent** mutant **or** the test cases do not reveal the error and **need to find a new test case** that does



Relay Model



Other Fault-Based techniques:

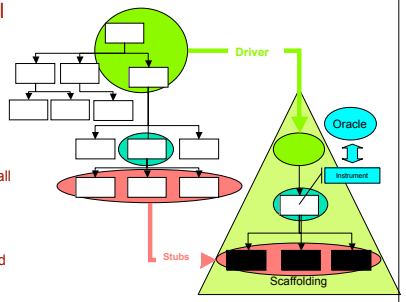
- mutating test data
  - instead of mutating program, mutate input
- Bart Miller did an experiment where he demonstrated that arbitrary strings caused UNIX to consistently fail
  - wanted to understand why storms caused his connection to go down

Putting it all together

- unit testing
- integration & system testing
- regression testing

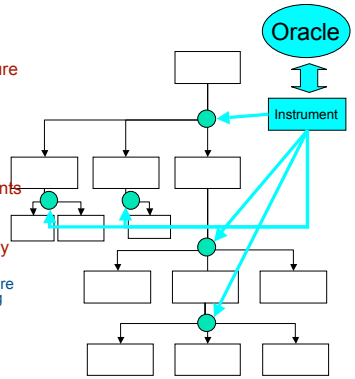
Unit testing

- test scaffolding
  - can be created for general or for specific tests
  - is composed of
    - one or more drivers
      - provide a prototype activation environment
      - drivers initialize non-local variables and parameters and call the unit
    - one or more stubs
      - provide a prototype of the units used by the program to be tested
    - one or more oracles
      - identify the tests that cause failures.



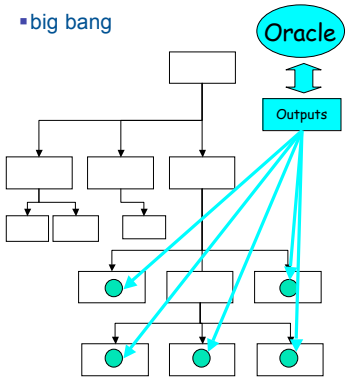
Unit vs. Integration vs. System Testing

- Integration testing
  - focuses on communication and interface problems
  - tests derived from module interfaces and detailed architecture specifications
  - some scaffolding is required
- System testing
  - focuses on the behavior of the system as a whole
  - tests are derived from requirements specifications
  - code is seen as a black box
  - support of scaffoldings not usually needed
    - exception is embedded code, where some simulation of the embedding environment may be required

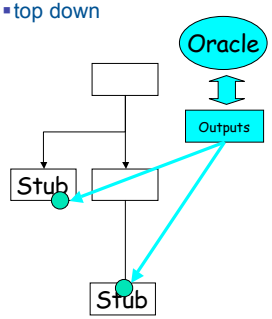


Integration testing strategies

- big bang

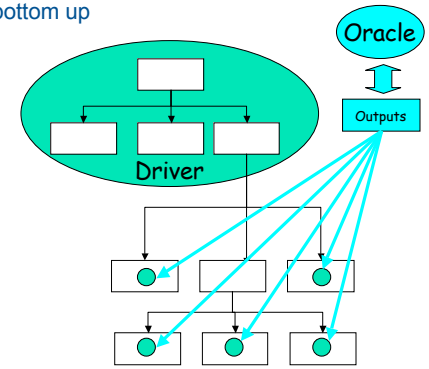


- top down

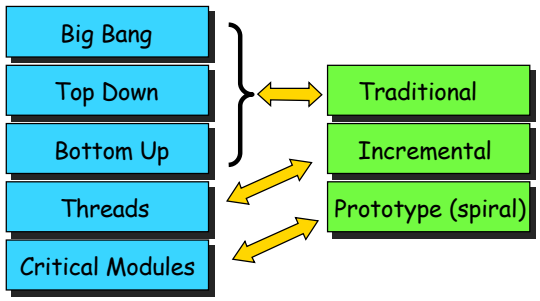


Integration testing strategies

- bottom up



Relation to design



O-O Programs are Different

- High Degree of Reuse
  - Does this mean more, or less testing?
- Unit Testing vs. Class Testing
  - What is the right "unit" in OO testing?
- Review of Analysis & Design
  - Classes appear early, so defects can be recognized early as well

Testing OOA and OOD Models

- Correctness (of each model element)
  - Syntactic (notation, conventions)
    - review by modeling experts
  - Semantic (conforms to real problem)
    - review by domain experts
- Consistency (of each class)
  - Revisit Class Diagram
  - Trace delegated responsibilities
  - Examine / adjust cohesion of responsibilities
- Evaluating the Design
  - Compare behavioral model to class model
  - Compare behavioral & class models to the use cases
  - Inspect the detailed design for each class (algorithms & data structures)

Unit Testing

- What is a "Unit"?
  - Traditional: a "single operation"
  - O-O: encapsulated data & operations
- Smallest testable unit = class
  many operations
- Inheritance
  - testing "in isolation" is impossible
  - operations must be tested every place they are used

Issues in O-O testing

- Need to re-examine all testing techniques and processes
  - Primary Issues:
    - implications of encapsulation
    - implications of inheritance
    - implications of genericity
    - implications of polymorphism
  - Changes concerns
    - State of instance variables
    - Sequences of methods calls
    - Must test a class and its specializations

Example

```
Base::describedSelf() is this code
        if (val < 0) message("Less")
        else if(val==0) message("Equal")
        else message("More")
```

```
Tests:
 input, expected output
  -1     Less
   0     Equal
   1     More
```

```
Tests:
 input, expected output
OK    -1     Less
Change 0     Equal- Zero Equal
OK     1     More
Add    42    Jackpot
```

```
Derived::describedSelf() is this code
        if (val < 0) message("Less")
        else if(val==0) message("Zero Equal")
        else
        {
            message("More")
            if(val==42) message("Jackpot")
        }
```


White-box vs. Black-box Testing

- The distance between object-oriented specification and implementation is typically small
  - gap (and therefore usefulness) of the white-box/black-box distinction is decreasing
- But object-oriented specification describes functional behavior, while the implementation describes how that is achieved
- These techniques can be adapted to method testing, but are not sufficient for class testing
- Conventional flow-graph approaches
  - may be inconsistent the object-oriented paradigm
  - method-level control faults are not likely

Black-box O-O Testing

- Conventional black-box methods are useful for object-oriented systems
  - error-guessing strategies
  - verification of ADTs can be adapted to object-oriented systems
- Other approaches
  - utilize specifications integrated with the implementation as assertions
    - specification integrated with the implementation as dynamic assertions
    - C++ assertions or Eiffel pre/post-conditions offer similar self-checking
  - Utilize method (event) sequence information
    - usually don't have history of method invocations so can't do this with assertions

Encapsulation

- not a source of errors but may be an obstacle to testing
- how to get at the concrete state of an object?
- use the abstraction
  - state is inspected via access methods
  - equivalence scenarios
    - comparing sequences of events
    - state is implicitly inspected by comparing related behavior
  - examine sequences of events
    - need to be able to define what are equivalent sequences and need to determine equal states
- use or provide hidden functions to examine the state
  - useful for debugging throughout the life of the system
    - but modified code, may alter the behavior
    - especially true for languages that do not support strong typing
- proof-of-correctness techniques
  - a proved method could be excused from testing to bootstrap testing of other methods
  - state reporting methods tend to be small and simple, they should be relatively easy to prove

Implications of Inheritance

- rule rather than the exception?
- inherited features usually require re-testing
  - because a new context of usage results when features are inherited
  - multiple inheritance increases the number of contexts to test
- specialization relationships
  - implementation specialization should correspond to problem domain specialization
  - reusability of superclass test cases depends on this

Which fns must be tested

Base class contains:
inherited(int x)
redefined() - returns a number in range 1 to 10 inclusive

Derived class contains:
redefined() - returns a number in range 0 to20 inclusive
//inherited() is inherited

- derived::redefined has to be tested afresh
- does derived::inherited() have to be retested?

```
inherited contains the code:
        if (x<0)
            x = x/redefined()
        return x
```

have to test when x<0, could divide by 0

- derived::inherited() may not have to be completely tested
  - if code in inherited() doesn't depend on redefined(), doesn't call it nor call any code that indirectly calls it

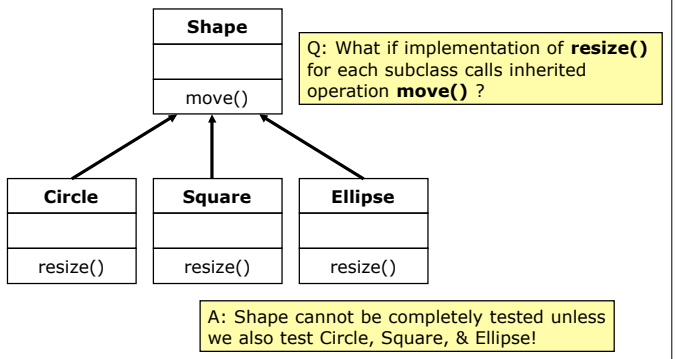
Inheritance Testing

- flattening inheritance
  - each subclass is tested as if all inherited features were newly defined
  - tests used in the super-classes can be reused
  - many tests are redundant
- incremental testing
  - reduce tests only to new/modified features
  - determining what needs to be tested requires automated support

Polymorphism

- in procedural programming, procedure calls are statically bound
- each possible binding of a polymorphic component requires a separate set of test cases
  - many server classes may need to be integrated before a client class can be tested
- may be hard to determine all such bindings
- complicates integration planning and testing

Testing under Inheritance



Integration Testing

- O-O Integration: Not Hierarchical
  - Coupling is not via subroutine
  - "Top-down" and "Bottom-up" have little meaning
- Integrating one operation at a time is difficult
  - Indirect interactions among operations

O-O Integration Testing

- Thread-Based Testing
  - Integrate set of classes required to respond to one input or event
  - Integrate one thread at a time
  - Example: Event-Dispatching Thread vs. Event Handlers in Java
    - Implement & test all GUI events first
    - Add event handlers one at a time
- Use-Based Testing
  - Implement & test independent classes first
  - Then implement dependent classes (layer by layer, or cluster-based)
  - Simple driver classes or methods sometimes required to test lower layers

COMPUTER SCIENCE

Test Case Design

- Focus: "Designing sequences of operations to exercise the states of a class instance"
- Challenges
  - Observability - Do we have methods that allow us to inspect the inner state of an object?
  - Inheritance - Can test cases for a superclass be used to test a subclass?
- Test Case Checklist
  - Identify unique tests & associate with a particular class
  - Describe purpose of the test
  - Develop list of testing steps:
    - Specified states to be tested
    - Operations (methods) to be tested
    - Exceptions that might occur
    - External conditions & changes thereto
    - Supplemental information (if needed)