Software Testing, Quality Assurance and Maintenance Winter 2015

Lecture 5 — January 14, 2015

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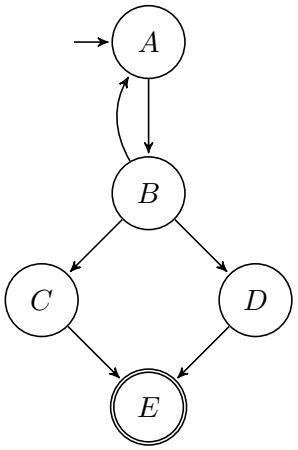
Graph Coverage

We will discuss graph coverage in great detail. Many forms of software testing reduce to graph coverage, so once you understand how graph coverage works, you will have a good understanding of a key software testing topic.

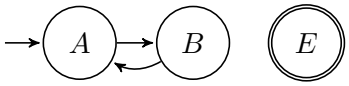
Definition of Graphs. (You should already be familiar with this material, but let's establish the terms we'll use in this class). Let's start with an example graph.



N : Set of nodes $\{A, B, C, D, E\}$
N_0 : Set of initial nodes $\{A\}$
N_f : Set of final nodes $\{E\}$
$E \subseteq N \times N$: Edges, e.g. (A, B) and (C, E);
C is the predecessor and
E is the successor in (C, E).

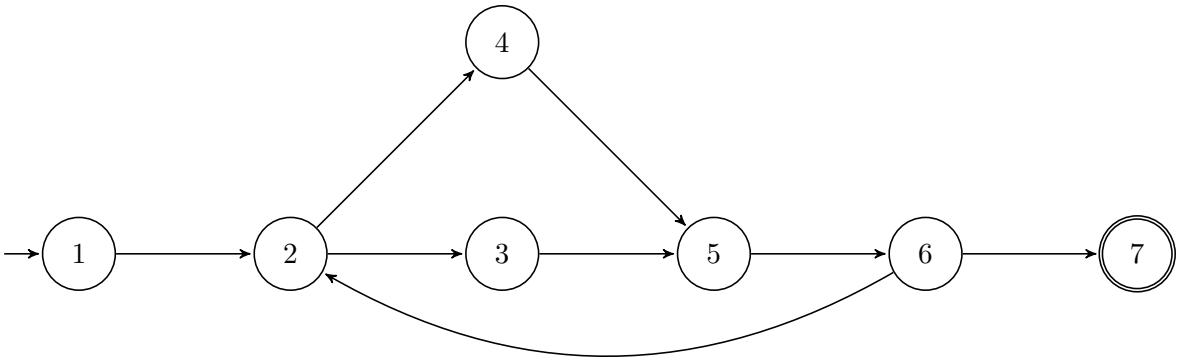
Subgraph: Let G' be a subgraph of G; then the nodes of G' must be a subset N_{sub} of N. Then the initial nodes of G' are $N_0 \cap N_{\text{sub}}$ and its final nodes are $N_f \cap N_{\text{sub}}$. The edges of G' are $E \cap (N_{\text{sub}} \times N_{\text{sub}})$.

For example, consider the case where we set $N_{\text{sub}} = \{A, B, E\}$. This induces the subgraph:



Note that graphs need not be connected.

Paths. The most important thing about a graph, for testing purposes, is the path through the graph. Here is a graph $G_{\#}$ and some example paths through the graph.



- path 1: $[2, 3, 5]$, with length 2.
- path 2: $[1, 2, 3, 5, 6, 2]$, with length 5.
- not a path: $[1, 2, 5]$.

We say that path 1 is *from* node 2 *to* node 5. We can also say that path 1 is *from* edge $(2, 3)$ *to* $(3, 5)$.

Definition 1 *A* path *is a sequence of nodes from a graph G whose adjacent pairs all belong to the set of edges E of G.*

Note that length 0 paths are still paths.

Definition 2 *A* subpath *is a subsequence of a path.*

This textbook definition is ambiguous: is $[1, 2, 5]$ a subpath of $[1, 2, 3, 5, 6, 2]$?

Definition 3 *A* subsequence *is a sequence that can be derived from another sequence by deleting some elements without changing the order of the remaining elements.*

Yes, $[1, 2, 5]$ is a subsequence of $[1, 2, 3, 5, 6, 2]$. However, $[1, 2, 5]$ is not a path, so we are going to say that it is not a subpath.

Test cases and test paths.

Some paths are also test paths. Here is a test path from $G_{\#}$:

$$[1, 2, 3, 5, 6, 7];$$

here is another one:

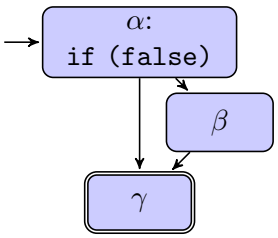
$$[1, 2, 3, 5, 6, 2, 3, 5, 6, 7].$$

You can easily come up with more paths. Now, test paths are linked to test cases. First, let's define the notion of a test path.

Definition 4 *A* test path *is a path p (possibly of length 0) that starts at some node in N_0 and ends at some node in N_f.*

Running the test case on the program or method yields one or more test paths. A test path may represent many test cases (for instance, if a program takes the same branches on all of those test cases); or a test path may represent no test cases (if it is infeasible).

Paths and semantics. When a graph is a program's control-flow graph, some of the paths in the graph may not correspond to program semantics. Consider the following graph.



Clearly β will never execute.

In this course, we will generally only talk about the *syntax* of a graph—its nodes and edges—and not its *semantics*.

However, in the following definition, we'll talk about both notions.

Definition 5 *A node n (or edge e) is* syntactically reachable *from n_i if there exists a path from n_i to n (or e). A node n (or edge e) is* semantically reachable *if one of the paths from n_i to n can be reached on some input.*

Standard graph algorithms, like breadth-first search and depth-first search, can compute syntactic reachability. (Semantic reachability is undecidable; no algorithm can precisely compute semantic reachability for all programs.)

We define $\text{reach}_G(\chi)$ as the portion of the graph syntactically reachable from χ. (χ might be a node, an edge, a set of nodes, or a set of edges.) For example:

- $\text{reach}_G(N_0)$ is the set of nodes and edges reachable from the initial node(s);
- $\text{reach}_{G\#}(2)$ in the above graph $G_\#$ is $\{2, 3, 4, 5, 6, 7\}$;
- $\text{reach}_{G\#}(7)$ is $\{7\}$.

Note that we include χ in the set of nodes reachable from χ, because paths of length 0 are paths.

When we talk about the nodes or edges in a graph G in a coverage criterion, we'll generally mean $\text{reach}_G(N_0)$; the unreachable nodes tend to (1) be uninteresting; and (2) to frustrate coverage criteria.