Software Engineering

Software Complexity Metrics

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Topics

- Measuring Software Complexity
- Cyclomatic Complexity

Measuring Software Complexity

- Software complexity is difficult to operationalize complexity so that it can be measured
- Computational complexity measure big O (or big Oh), O(n)
  - Measures software complexity from the *machine's viewpoint* in terms of how the size of the input data affects an algorithm's usage of computational resources (usually running time or memory)
- Complexity measure in software engineering should measure complexity from the *viewpoint of human developers*

Cyclomatic Complexity

- Invented by Thomas McCabe (1974) to measure the complexity of a program's conditional logic
  - Counts the number of decisions in the program, under the assumption that decisions are difficult for people
  - Makes assumptions about decision-counting rules and linear dependence of the total count to complexity
- Cyclomatic complexity of graph G equals #edges - #nodes + 2
  - $V(G) = e - n + 2$
- Also corresponds to the number of linearly independent paths in a program (described later)

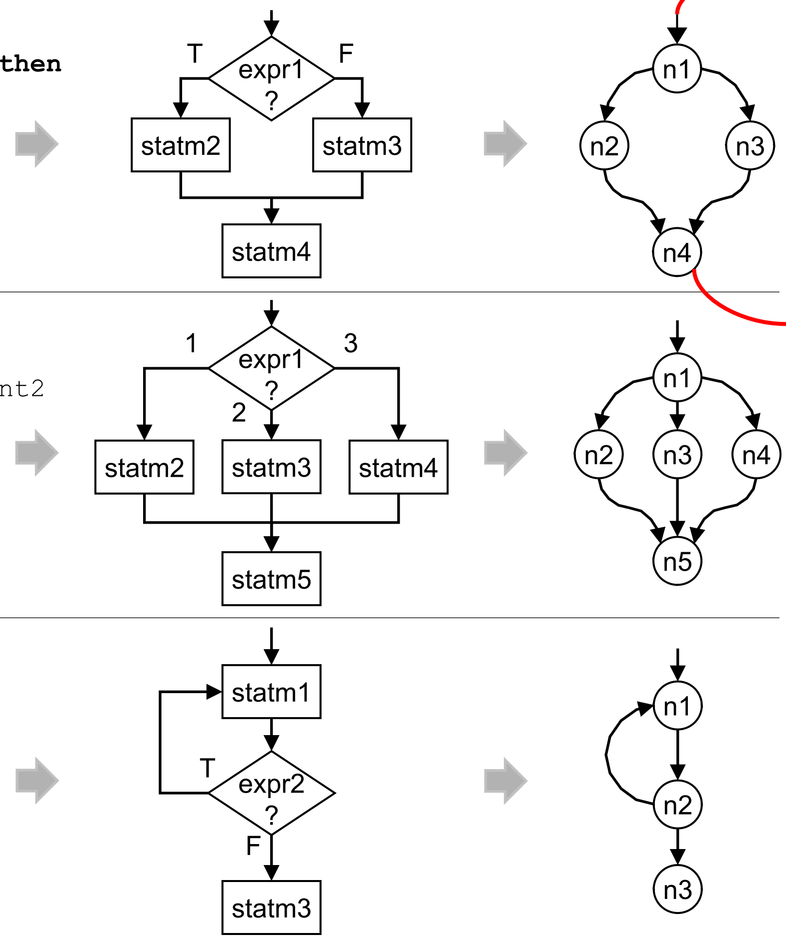
Converting Code to Graph

	CODE	FLOWCHART	GRAPH

(a)	**if** expression1 **then**
	    statement2
	else
	    statement3
	end if
	statement4		

(b)	**switch** expr1
	    case 1:
	        statement2
	    case 2:
	        statm3
	    case 3:
	        statm4
	end switch
	statm5		

(c)	**do**
	    statement1
	  while expr2
	end do
	statement3		



For a strongly connected graph:
Create a ***virtual edge***
to connect the END node
to the BEGIN node

Paths in Graphs (1)

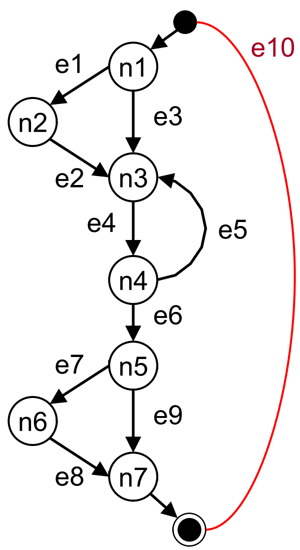
- *A* graph is **strongly connected** if for any two nodes *x*, *y* there is a path from *x* to *y* and vice versa
- *A* **path** is represented as an *n*-element vector where *n* is the number of edges
  <□, □, ..., □>
- The *i*-th position in the vector is the number of occurrences of edge *i* in the path

Example Paths

```
if expression1 then
    statement2
end if

do
    statement3
  while expr4
end do

if expression5 then
    statement6
end if
statement7
```



Paths:	e1	e2	e3	e4	e5	e6	e7	e8	e9	e10
P1 = e1, e2, e4, e6, e7, e8	1,	1,	0,	1,	0,	1,	1,	1,	0,	0
P2 = e1, e2, e4, e5, e4, e6, e7, e8	1,	1,	0,	2,	1,	1,	1,	1,	0,	0
P3 = e3, e4, e6, e7, e8, e10	0,	0,	1,	1,	0,	1,	1,	1,	0,	1
P4 = e6, e7, e8, e10, e3, e4	0,	0,	1,	1,	0,	1,	1,	1,	0,	1
P5 = e1, e2, e4, e6, e9, e10	1,	1,	0,	1,	0,	1,	0,	0,	1,	1
P6 = e4, e5	0,	0,	0,	1,	1,	0,	0,	0,	0,	0
P7 = e3, e4, e6, e9, e10	0,	0,	1,	1,	0,	1,	0,	0,	1,	1
P8 = e1, e2, e4, e5, e4, e6, e9, e10	1,	1,	0,	2,	1,	1,	0,	0,	1,	1

<u>NOTE</u>: A path does not need to start in node n1 and does not need to begin and end at the same node. E.g.,

- Path P4 starts (and ends) at node n4
- Path P1 starts at node n1 and ends at node n7

Paths in Graphs (2)

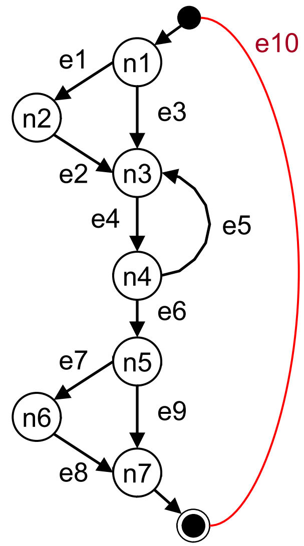
- A **circuit** is a path that begins and ends at the same node
  - e.g., P3 = <e3, e4, e6, e7, e8, e10> begins and ends at node n1
  - P6 = <e4, e5> begins and ends at node n3
- A **cycle** is a circuit with no node (other than the starting node) included more than once

Example Circuits & Cycles

```
if expression1 then
    statement2
end if

do
    statement3
  while expr4
end do

if expression5 then
    statement6
end if
statement7
```



Circuits:

	e1	e2	e3	e4	e5	e6	e7	e8	e9	e10
P3 = e3, e4, e6, e7, e8, e10	0,	0,	1,	1,	0,	1,	1,	1,	0,	1
P4 = e6, e7, e8, e10, e3, e4	0,	0,	1,	1,	0,	1,	1,	1,	0,	1
P5 = e1, e2, e4, e6, e9, e10	1,	1,	0,	1,	0,	1,	0,	0,	1,	1
P6 = e4, e5	0,	0,	0,	1,	1,	0,	0,	0,	0,	0
P7 = e3, e4, e6, e9, 10	0,	0,	1,	1,	0,	1,	0,	0,	1,	1
P8 = e1, e2, e4, e5, e4, e6, e9, e10	1,	1,	0,	2,	1,	1,	0,	0,	1,	1
P9 = e3, e4, e5, e4, e6, e9, 10	0,	0,	1,	2,	1,	1,	0,	0,	1,	1

Cycles:

P3 = e3, e4, e6, e7, e8, e10

P5 = e1, e2, e4, e6, e9, e10

P6 = e4, e5

P7 = e3, e4, e6, e9, 10

Linearly Independent Paths

- A path p is said to be a **linear combination** of paths $p_1, \ldots, p_n$ if there are integers $a_1, \ldots, a_n$ such that $p = \sum a_i \cdot p_i$
- A set of paths is **linearly independent** if no path in the set is a linear combination of any other paths in the set
- A **basis set** of *cycles* is a maximal linearly independent set of cycles
  - In a graph with e edges and n nodes, the basis has $e - n + 1$ cycles
- Every path is a linear combination of basis cycles

Baseline method for finding the basis set of cycles

- Start at the source node
- Follow the leftmost path until the sink node is reached
- Repeatedly retrace this path from the source node, but change decisions at every node with out-degree ≥2, starting with the decision node lowest in the path

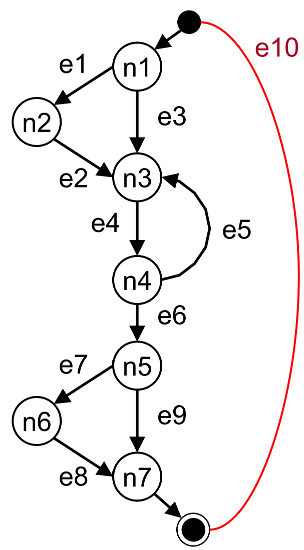
T.J. McCabe & A.H. Watson, *Structured Testing: A Testing Methodology Using the Cyclomatic Complexity Metric*, NIST Special Publication 500-235, 1996.

Linearly Independent Paths

```
if expression1 then
    statement2
end if

do
    statement3
  while expr4
end do

if expression5 then
    statement6
end if
statement7
```



V(G) = e – n + 2 = 9 – 7 + 2 = 4

Or, if we count e10, then e – n + 1 = 10 – 7 + 1 = 4

Paths:

Path	e1	e2	e3	e4	e5	e6	e7	e8	e9	e10
P1 = e1, e2, e4, e6, e7, e8	1	1	0	1	0	1	1	1	0	0
P2 = e1, e2, e4, e5, e4, e6, e7, e8	1	1	0	2	1	1	1	1	0	0
P3 = e3, e4, e6, e7, e8, e10	0	0	1	1	0	1	1	1	0	1
P4 = e6, e7, e8, e10, e3, e4	0	0	1	1	0	1	1	1	0	1
P5 = e1, e2, e4, e6, e9, e10	1	1	0	1	0	1	0	0	1	1
P6 = e4, e5	0	0	0	1	1	0	0	0	0	0
P7 = e3, e4, e6, e9, 10	0	0	1	1	0	1	0	0	1	1
P8 = e1, e2, e4, e5, e4, e6, e9, e10	1	1	0	2	1	1	0	0	1	1

Cycles:

P3 = e3, e4, e6, e7, e8, e10

P5 = e1, e2, e4, e6, e9, e10

P6 = e4, e5

P7 = e3, e4, e6, e9, 10

EXAMPLE #1: P5 + P6 = P8

P5	{1, 1, 0, 1, 0, 1, 0, 0, 1, 1}
+ P6	{0, 0, 0, 1, 1, 0, 0, 0, 0, 0}
= P8	{1, 1, 0, 2, 1, 1, 0, 0, 1, 1}

EXAMPLE #2: 2×P3 – P5 + P6 =

2×P3	{ 0, 0, 2, 2, 0, 2, 2, 2, 0, 2}
– P5	{ 1, 1, 0, 1, 0, 1, 0, 0, 1, 1}
	{-1,-1, 2, 1, 0, 1, 2, 2,-1, 1}
+ P6	{ 0, 0, 0, 1, 1, 0, 0, 0, 0, 0}
= P?	{-1,-1, 2, 2, 1, 1, 2, 2,-1, 1}

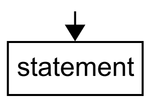
Unit Testing: Path Coverage

  - Finds the number of distinct paths through the program to be traversed at least once

- Minimum number of tests necessary to cover all edges is equal to the **number of independent paths** through the control-flow graph

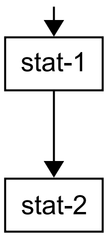
Issues (1)

Single statement:



= CC =

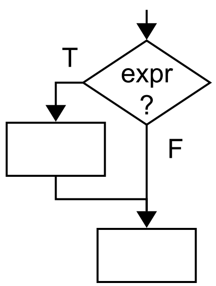
Two (or more) statements:



Cyclomatic complexity (CC) remains the same for a linear sequence of statements regardless of the sequence length
—insensitive to complexity contributed by the multitude of statements

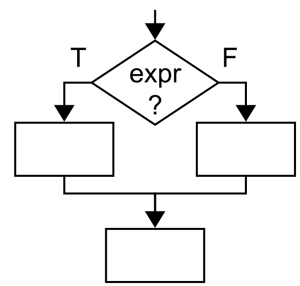
Issues (2)

Optional action:



= CC =

Alternative choices:

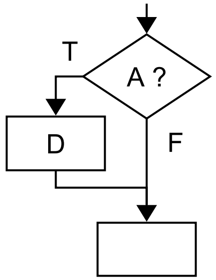


Optional action versus alternative choices —
the latter is psychologically more difficult

Issues (3)

Simple condition:

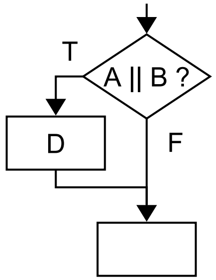
```
if (A) then D;
```



= CC =

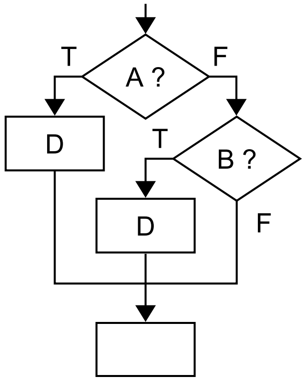
Compound condition:

```
if (A OR B) then D;
```



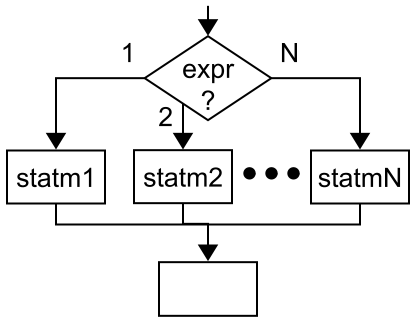
BUT, compound condition can be written as a nested IF:

```
if (A) then D;
else if (B) then D;
```



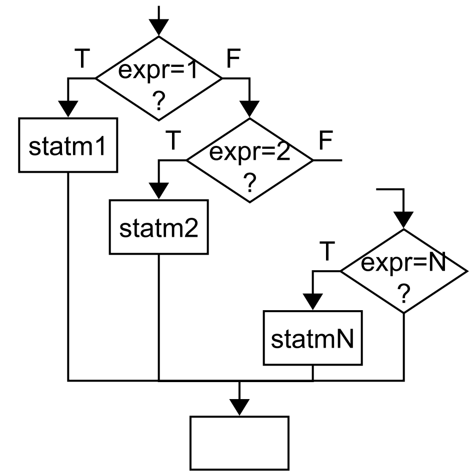
Issues (4)

Switch/Case statement:



= CC =

N–1 predicates:



<u>Counting a **switch** statement</u>:

—as a single decision

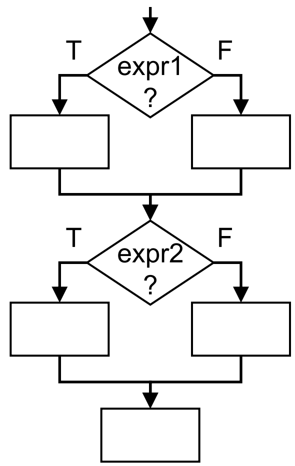
proposed by W. J. Hansen, "Measurement of program complexity by the pair (cyclomatic number, operator count)," *SIGPLAN Notices*, vol.13, no.3, pp.29-33, March 1978.

—as $\log_2(N)$ relationship

proposed by V. Basili and R. Reiter, "Evaluating automatable measures for software development," *Proceedings of the IEEE Workshop on Quantitative Software Models for Reliability, Complexity and Cost*, pp.107-116, October 1979.

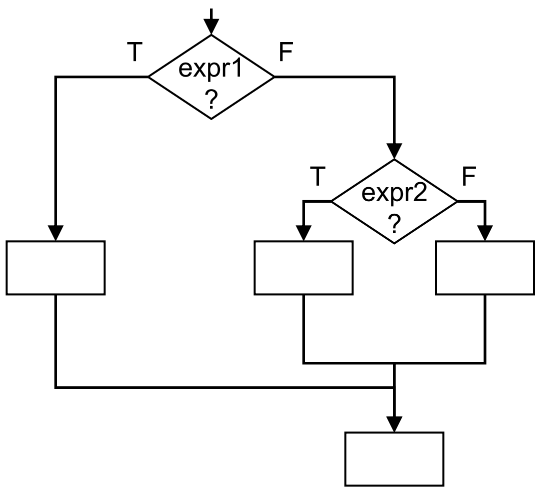
Issues (5)

Two sequential decisions:



= CC =

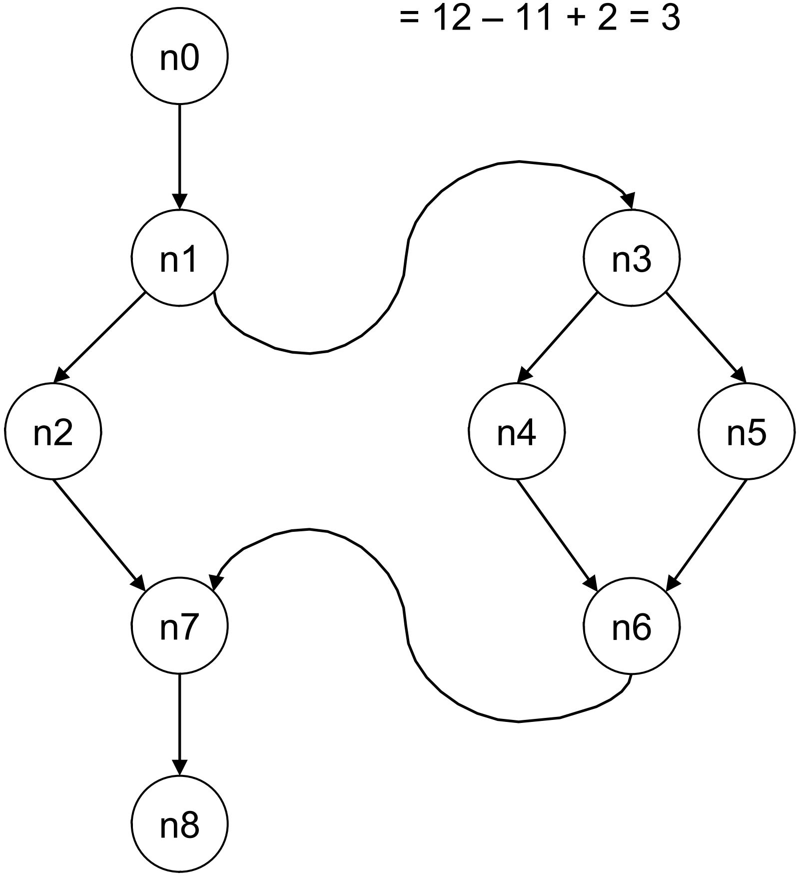
Two nested decisions:



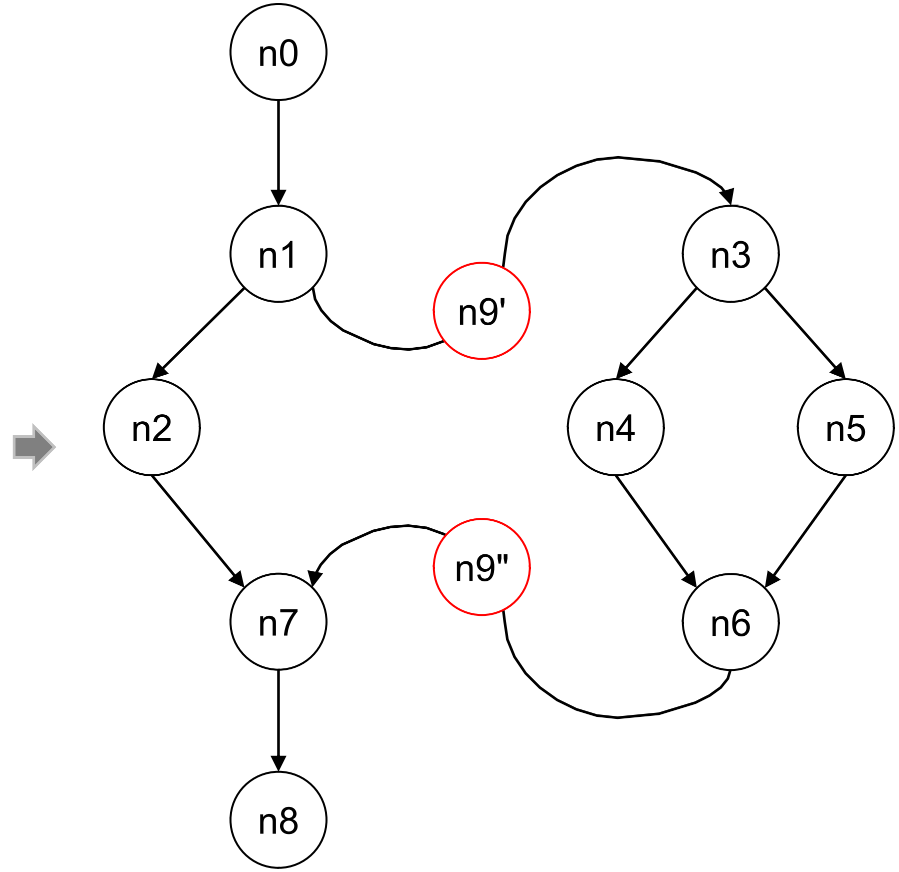
But, it is known that people find nested decisions more difficult …

CC for Modular Programs (1)

$V = e - n + 2$
$= 12 - 11 + 2 = 3$



Adding a sequential node does not change CC:

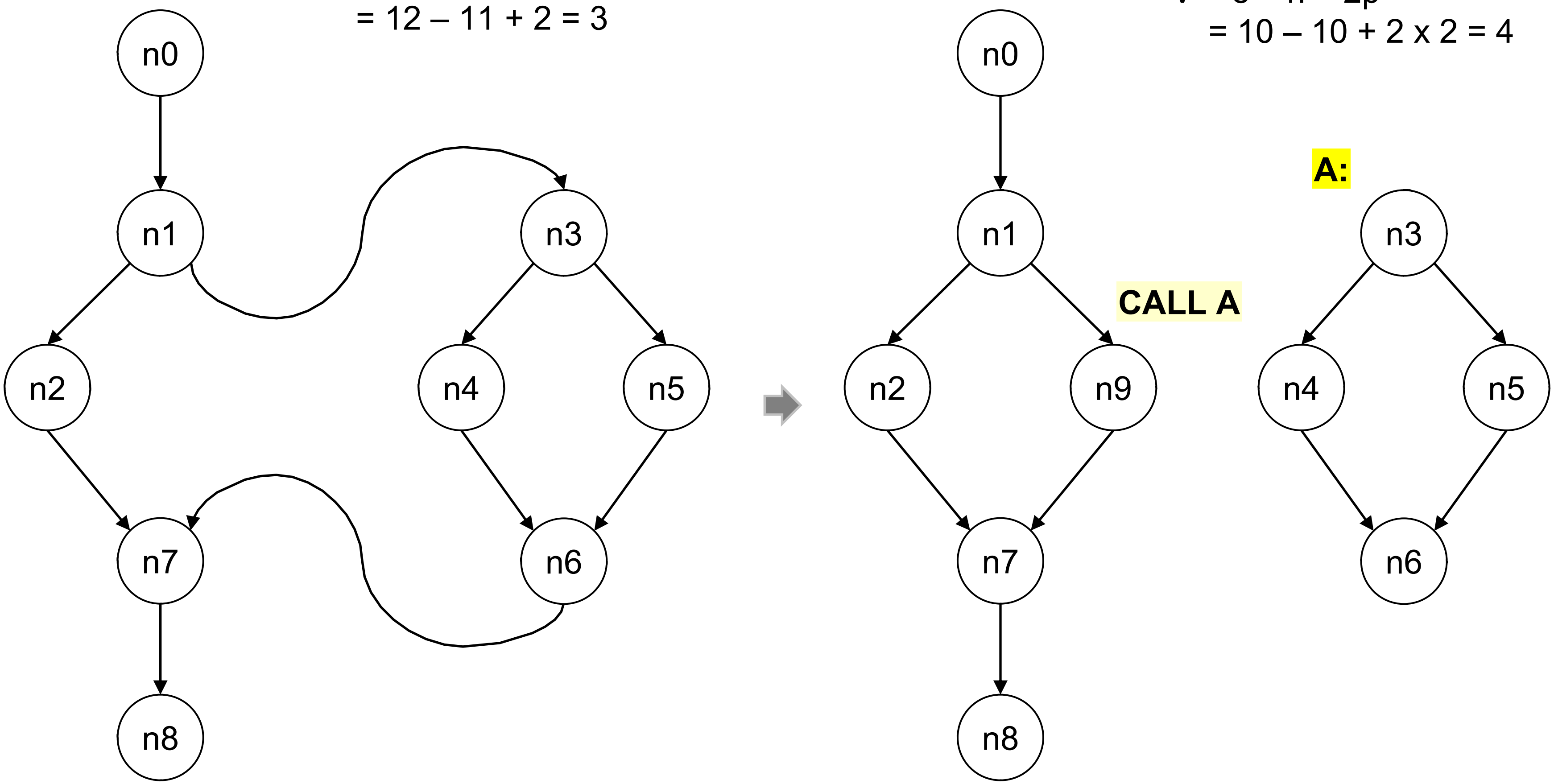


CC for Modular Programs (2)

Intuitive expectation:
Modularization should not increase complexity

$$V = e - n + 2 = 12 - 11 + 2 = 3$$

$$V = e - n + 2p = 10 - 10 + 2 \times 2 = 4$$



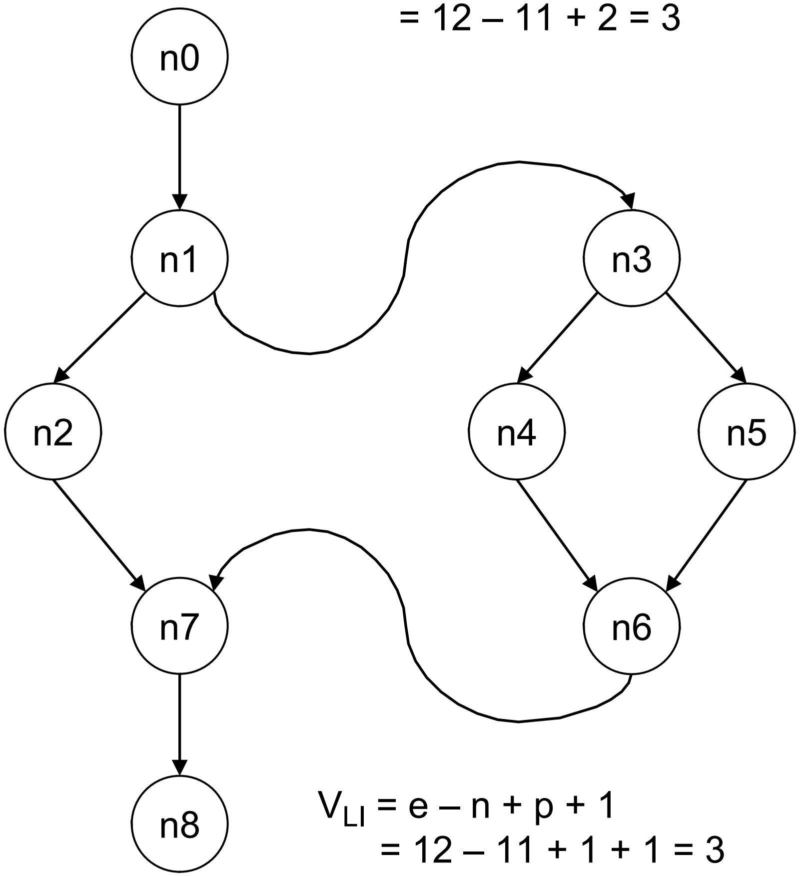
Alternative CC Measures

- Given ***p*** connected components of a graph:
  - $V(G) = e - n + 2p$ (1)
  - $V_{LI}(G) = e - n + p + 1$ (2)
  - Eq. (2) is known as *linearly-independent* cyclomatic complexity
  - V_{LI} does not change when program is modularized into *p* modules

CC for Modular Programs (3)

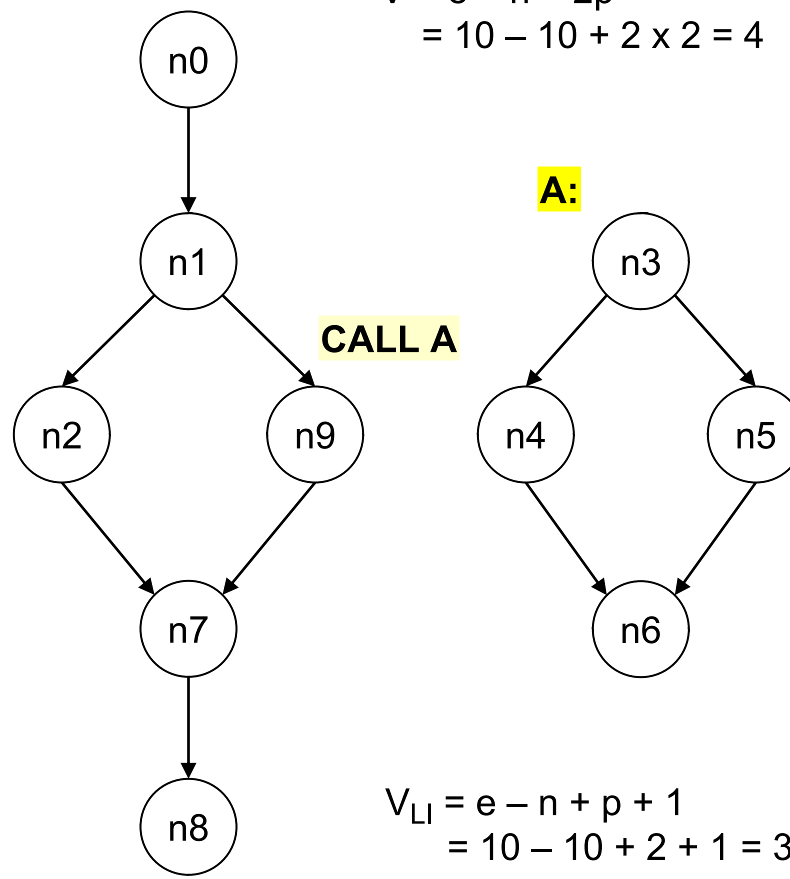
Intuitive expectation:
Modularization should not increase complexity

$V = e - n + 2$
$= 12 - 11 + 2 = 3$



$V_{LI} = e - n + p + 1$
$= 12 - 11 + 1 + 1 = 3$

$V = e - n + 2p$
$= 10 - 10 + 2 \times 2 = 4$



$V_{LI} = e - n + p + 1$
$= 10 - 10 + 2 + 1 = 3$

Practical SW Quality Issues

- No program module should exceed a cyclomatic complexity of 10
  - P. Jorgensen, *Software Testing: A Craftman's Approach, 2nd Edition*, CRC Press Inc., pp.137-156, 2002 .
- Software refactorings are aimed at reducing the complexity of a program's conditional logic

Refactoring: Improving the Design of Existing Code
by **Martin Fowler**, et al.
Addison-Wesley Professional, 1999.