Software Engineering

Lecture-14

Metrics

Topics Covered

- Introduction
- Attributes Of Effective Software Metrics
- Metrics for SRS Attributes
- Component-level Design Metrics

DEFINITION

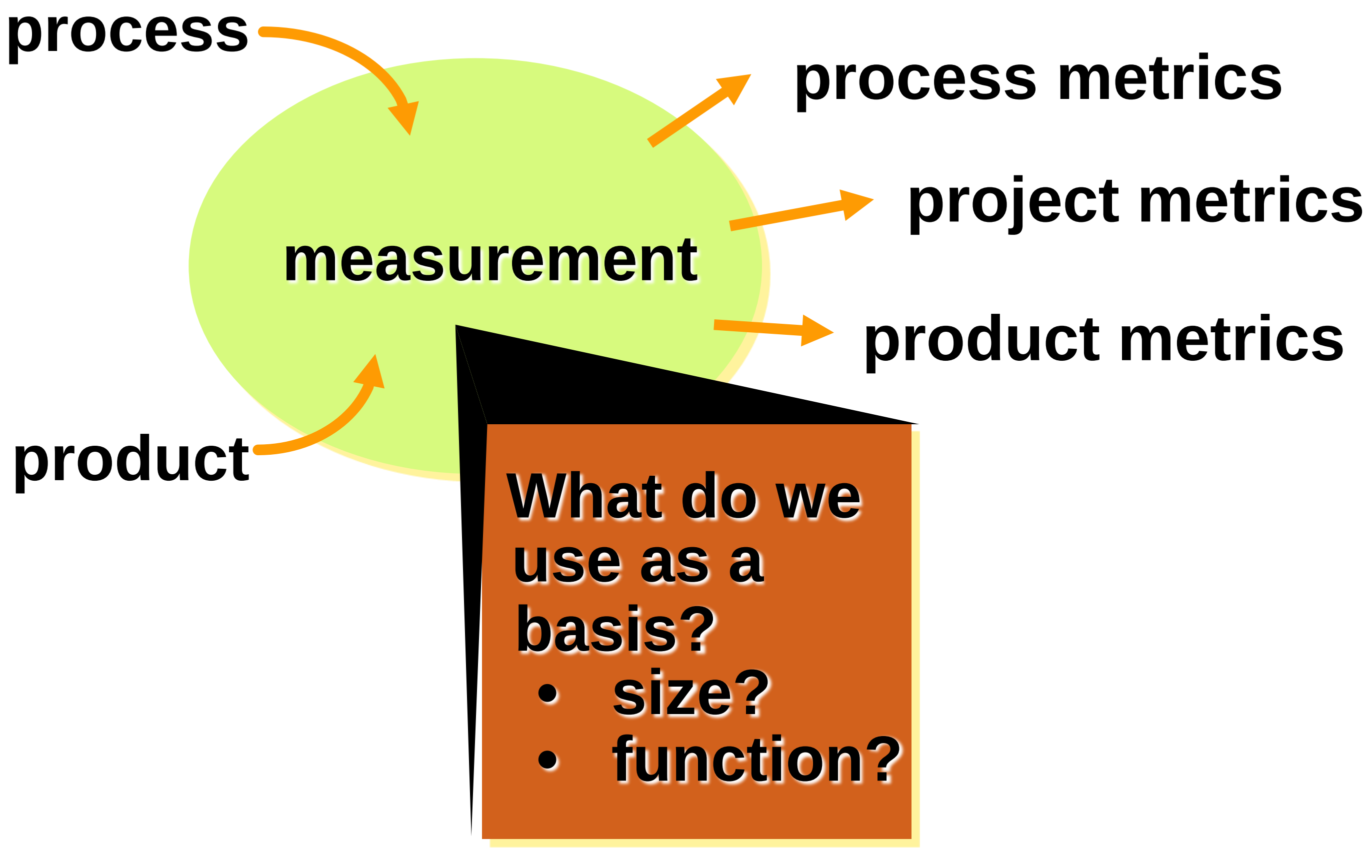
- **Measure**: A quantitative indication of the extent, amount, dimensions, capacity, or size of some attribute of a product or process.
- **Metric**: A quantitative measure of the degree to which a system, component, or process possesses a given attribute.

  A comparison of 2 or more measures.
- **Indicator**:A metric or combination of metrics that provide insight into the software process, a software project or the product.

Why Do We Measure?

- ***To understand*** what is happening during development and maintenance.
- ***To control*** what is happening on our projects.
- ***To improve*** our process and products.

A Good Manager Measures



Process Metrics

- majority focus on quality achieved as a consequence of a repeatable or managed process
- statistical SQA data
  - error categorization & analysis
- defect removal efficiency
  - propagation from phase to phase

Defect Removal Efficiency

DRE = (errors) / (errors + defects)

where

errors = problems found before release

defects = problems found after release

Project Metrics

- **Objectives:**
  - To minimize the development schedule
  - To assess product quality on an ongoing basis.
- **Examples:**
  - Effort/time per SE task
  - Errors uncovered per review hour
  - Scheduled vs. actual milestone dates
  - Changes (number) and their characteristics
  - Distribution of effort on SE tasks

Product Metrics

- **Objectives:**
  - focus on the quality of deliverables
- **Examples:**
  - measures of analysis model
  - complexity of the design
    - internal algorithmic complexity
    - architectural complexity
    - data flow complexity
  - code measures (e.g., Halstead)
  - measures of process effectiveness
    - e.g., defect removal efficiency

Measurement Process

- Formulation
- Collection
- Analysis
- Interpretation
- Feedback

Formulation Principles

- The objectives of measurement should be established before data collection begins
- Each technical metric should be defined in an unambiguous manner.
- Metrics should be derived based on a theory that is valid for the domain of application.
- Metrics should be tailored to best accommodate specific products and processes.

Collection & Analysis Principles

- Whenever possible, data collection and analysis should be automated.
- Valid statistical techniques should be applied to establish relationships between internal product attributes and external quality characteristics.
- Interpretative guidelines and recommendations should be established for each metric.

Attributes Of Effective Software Metrics

- Simple and Computable
- Empirically and Intuitively
- Consistent and Objective
- Programming language independent
- An effective mechanism for quality feedback

Measuring Software Quality: McCall's Quality Factors

- **Product Operation**
  - Correctness
  - Reliability
  - Usability
  - Integrity
  - Efficiency
- **Product Revision**
  - Maintainability
  - Testability
  - Flexibility
- **Product Transition**
  - Reusability
  - Portability
  - Interoperability

Measuring Software Quality: McCall's Quality Factors

Reliability
- Consistency
- Accuracy
- Error-tolerance
- Simplicity

Maintainability
- Concision
- Consistency
- Modularity
- Self-documentation
- simplicity

Measuring Quality in Software Requirements Specification (SRS)

- Unambiguous
- Complete
- Correct
- Understandable
- Verifiable
- Internally consistent
- Externally consistent
- Achievable
- Concise
- Design independent
- Traceable
- Modifiable
- Electronically stored
- Executable/Interpretable
- Annotated by relative importance
- Annotated by relative stability
- Annotated by version
- Not redundant
- At right level of detail
- Precise
- Reusable
- Traced
- Organized
- Cross-referenced

METRICS FOR SRS ATTRIBUTES

- n_f = functional requirements
- n_{nf} = non-functional requirements
- n_r = total requirements = $n_f + n_{nf}$

UNAMBIGUOUS

- A SRS is unambiguous if and only if every requirement stated therein has only one possible interpretation.
- Metric:

$$Q_1 = \frac{n_{ui}}{n_r}$$

n_{ui} is the number of requirements for which all reviewers presented identical interpretations.

0 - every requirement has multiple interpretation

1 - every requirement has a unique interpretation

Completeness

- A SRS is complete if everything that the software is supposed to do is included in the SRS.
- Metric:

$$Q_2 = \frac{n_A}{n_r}$$

  - n_A is the number of requirements in block A

CORRECTNESS

- A SRS is correct if and only if every requirement represents something required of the system to be built
- Metric:

$$Q_3 = \frac{n_C}{n_C + n_I}$$

  - n_C is the number of correct requirements
  - n_I is the number of incorrect requirements

UNDERSTANDABLE

- A SRS is understandable if all classes of SRS readers can easily comprehend the meaning of all requirements with a minimum of explanation.
- Metric:

$$Q_4 = \frac{n_{ur}}{n_r}$$

n_{ur} is the number of requirements for which all reviewers thought they understood.

CONCISE

- A SRS is concise if it is as short as possible without adversely affecting any other quality of the SRS.
- Metric:

$$Q_5 = \frac{1}{size + 1}$$

  - size is the number of pages

NOT REDUNDANT

- A SRS is redundant if the same requirement is stated more than one.
- Metric:

$$Q_6 = \frac{n_f}{n_u}$$

  - n_f is the actual functions specified
  - n_u is the actual unique functions specified

High-level Design Metrics

- High-level design metrics focus on characteristics of the program architecture with an emphasis on the architectural structural and the effectiveness of modules
- Metrics:
  - Card and Glass (1990)
  - Henry and Kafura (1981)
  - Fenton (1991)

Card And Glass (1990)

- 3 software design complexity measures:
  - structural complexity
  - data complexity
  - system complexity

Card and Glass (1990)

- Structural complexity (S(*i*))

$$S(i) = f_{out}^2(i)$$

where f_{out} is the fan-out of module *i*

- Data complexity (D(*i*))

$$D(i) = v(i) / [f_{out}^2(i) + 1]$$

where v(*i*) is the number of input and output variables that are passed to and from module *i*

- System complexity (C(*i*))

$$C(i) = S(i) + D(i)$$

Henry & Kafura (1981)

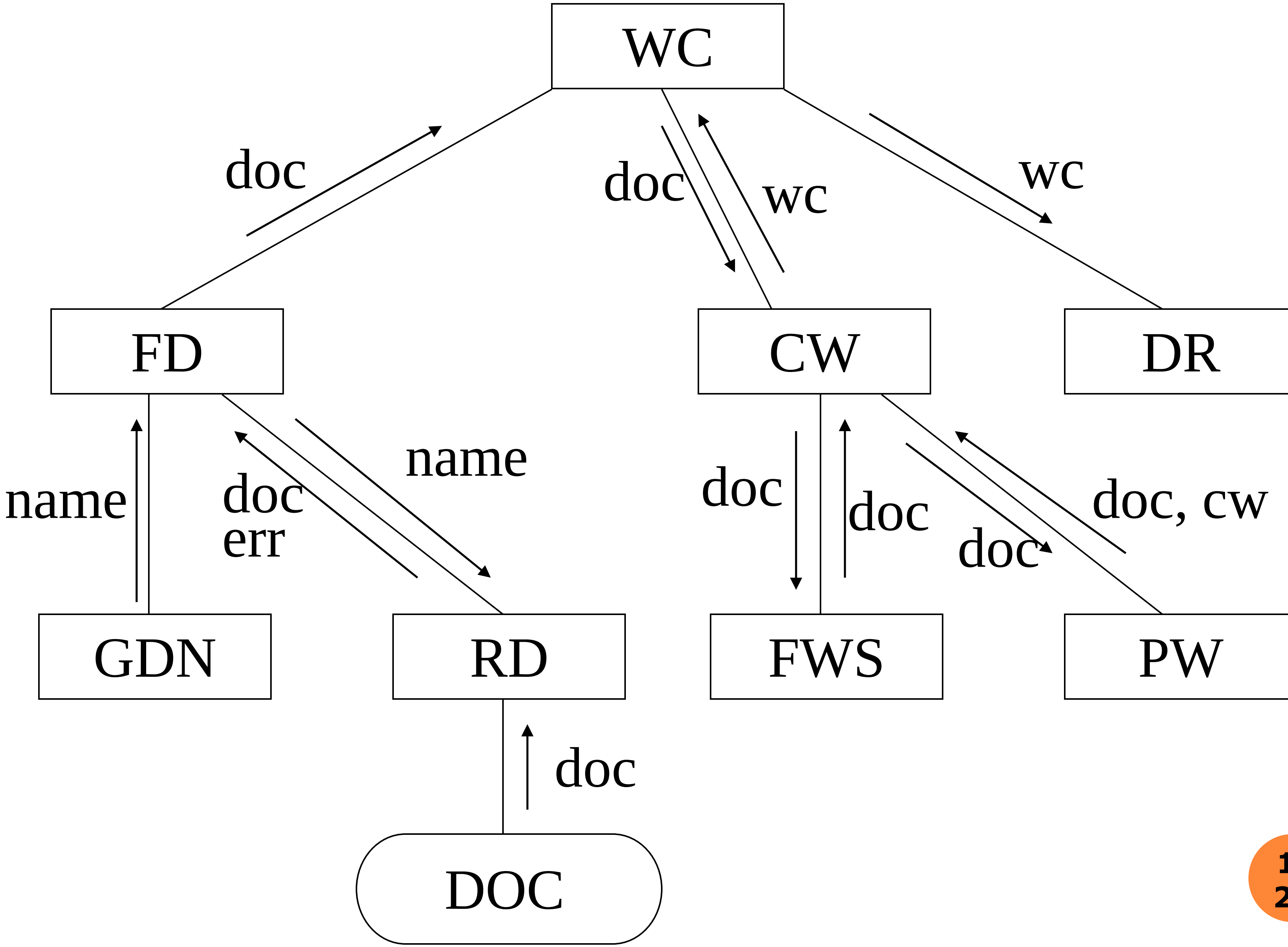
$$Complexity = length(i) \times [f_{in}(i) + f_{out}(i)]^2$$

where length (i) = the number of programming language statements in module i

$f_{in}(i)$ = the number of fan-in of module i

$f_{out}(i)$ = the number of fan-out of module i

- fan-in = the number of local flows of information that terminate at a module + the number of data structures from which information is retrieved.
- Fan-out = the number of local flows of information that emanate from a module plus_the number of data structures that are updated by that module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Fenton (1991)

- Measure of the connectivity density of the architecture and a simple indication of the coupling of the architecture.

  r = a/n

  r = arc-to-node ratio

  a = the number of arcs (lines of control)

  n = the number of nodes (modules)

- Depth = the longest path from the root (top) to a leaf node
- Width = maximum number of nodes at any one level of the architecture

Component-level Design Metrics

- Cohesion Metrics
  - Bieman and Ott (1994)
- Coupling Metrics
  - Dhama (1995)
- Complexity Metrics
  - McCabe (1976)

BIEMAN AND OTT (1994)

- Data slice is a backward walk through a module that looks for data values that affect the module location at which the walk began.
- Data token are variables and constants defined for a module.
- Glue tokens are data tokens that lie on one or more data slice.
- Superglue tokens are the data tokens that are common to every data slice in a module.

Bieman and Ott (1994)

- Strong functional cohesion (SFC)

  SFC(i) = SG(SA(i))/tokens (i)

  SG(SA(i)) = superglue tokens

PROCEDURE SUM AND PRODUCT

```
(N  : Integer;
 Var   SumN, ProdN : Integer);
Var              I  : Integer
Begin
  SumN         : = 0;
  ProdN        : = 1;
  For   I      : =   1  to   N   do begin
       SumN : =    SumN   +   I
       ProdN: =   ProdN    +   I
  End;
End;
```

Data Slide for SumN

```
( N  : Integer;
 Var   SumN, ProdN : Integer);
Var                I  : Integer
Begin
    SumN        : = 0;
    ProdN       : = 1;
    For  I      : =   1  to  N   do begin
          SumN : =    SumN   +   I
          ProdN: =   ProdN    +   I
    End;
End;
```

Data Slice for SumN = $N_1 \cdot SumN_1 \cdot I_1 \cdot SumN_2 \cdot 0_1 \cdot I_2 \cdot 1_2 \cdot N_2 \cdot SumN_3 \cdot SumN_4 \cdot I_3$

Data Slide for ProdN

```
(        : Integer;
 Var   SumN,            : Integer);
Var                    : Integer
Begin
   SumN          : = 0;
                 : =   ;
   For           : =      to       do begin
         SumN : =   SumN   +   I
                : =            +
   End;
End;
```

Data Slice for ProdN = $N_1 \cdot ProdN_1 \cdot I_1 \cdot ProdN_2 \cdot 1_1 \cdot I_2 \cdot 1_2 \cdot N_2 \cdot ProdN_3 \cdot ProdN_4 \cdot I_4$

Data token	SumN	ProdN
N_1	1	1
$SumN_1$	1	
$ProdN_1$		1
I_1	1	1
$SumN_2$	1	
0_1	1	
$ProdN_2$		1
1_1		1
I_2	1	1
1_2	1	1
N_2	1	1
$SumN_3$	1	
$SumN_4$	1	
I_3	1	
$ProdN_3$		1
$ProdN_4$		1
I_4		1

SUPER GLUE

S_1	S_2	S_3	
I	I	I	Super Glue
I			
	I		
		I	
I	I	I	Super Glue
	I		
I	I		Glue
	I	I	Glue

Functional Cohesion

- Strong functional cohesion (SFC)

  SFC(i) = SG(SA(i))/tokens (i)

  SG(SA(i)) = superglue tokens

  SG(SumAndProduct) = 5/17 = 0.204

DHAMA (1995)

- Data and control flow coupling
  - d_i = number of input data parameters
  - c_i = number of input control parameters
  - d_o = number of output data parameters
  - c_o = number of output control parameters
- Global coupling
  - g_d = number of global variables used as data
  - g_c = number of global variables used as control
- Environmental coupling
  - w = number of modules called (fan-out)
  - r = number of modules calling the module under consideration (fan-in)

DHAMA (1995)

- Coupling metric (m_c)

  $m_c = k/M$, where $k = 1$

  $M = d_i + a^* c_i + d_o + b^* c_o + c^* g_c + w + r$

  where a=b=c=2

Coupling Metric - Example

MODULE 1

```
Package sort1 is
type array_type is arrary (1..1000) of integer;
procedure sort1 (n: in integer;
    to_be_sorted: in out array_type;
    a_or_d: in character) is
location, temp: integer;
begin
    for start in 1..n loop
    location := start;

loop to get min or max each time
for i in (start + 1)..n loop
    if a_or_d = ‘d’ then
            if to_be_sorted(i) > to_be_sorted(location) then
               location := i;
            endif;
    else if to_be_sorted(i) < to_be_sorted(location)            then
               location := i;
    endif
endloop;
    temp := to_be_sorted(start);
    to_be_sorted(start) := to_be_sorted(location);
    to_be_sorted(location) := temp;
endloop
```

COUPLING METRIC - EXAMPLE

```
MODULE2
Package sort2 is
type array_type is arrary (1..1000) of integer;
Procedure sort2 (n: in integer;
   to_be_sorted: in out array_type;
   a_or_d: in character);
procedure find_max (n: in integer;
   to_be_sorted: in out array_type;
   location: in out integer);
procedure find_min (n, start: in integer;
   to_be_sorted: in out array_type;
   location: in out integer);
procedure exchange (start: in integer;
   to_be_sorted: in out array_type;
   location: in out integer);
endsort2;
```

Coupling Metric - Example

```
procedure find_max (n, start : in
   integer; to_be_sorted: in out
   array_type; location: in out
   integer); is
begin
   location := start;
   for i in start + 1..n loop
   if to_be_sorted(i) >
          to_be_sorted(location)
   then
          location := i;
   endif;
   endloop
end find_max;
```

```
procedure find_min (n, start: in
   integer; to_be_sorted: in out
   array_type; location: in out
   integer) is
begin
   location := start;
   for i in start + 1..n loop
   if to_be_sorted(i) <
          to_be_sorted(location)
   then
          location := i;
   endif;
   endloop
end find_min;
```

Coupling Metric - Example

```
procedure exchange (start: in
    integer; to_be_sorted: in out
    array_type; location: in out
    integer) is
temp: integer;
begin
temp := to_be_sorted(start);
to_be_sorted(start) :=
    to_be_sorted(location);
to_be_sorted(location) := temp;
end exchange;
```

```
Procedure sort2 (n: in integer;
    to_be_sorted: in out array_type;
    a_or_d: in character)is
location : integer;
begin
    for start in 1..n loop
        if a_or_d = ‘d’ then
            find_max(n, start, to_be_sorted,
                location);
        else
            find_min(n, start, to_be_sorted,
                location);
        endif;
            exchange(start, to_be_sorted,
                location);
    endloop;
end sort2;
end sort2;
```

McCabe (1976)

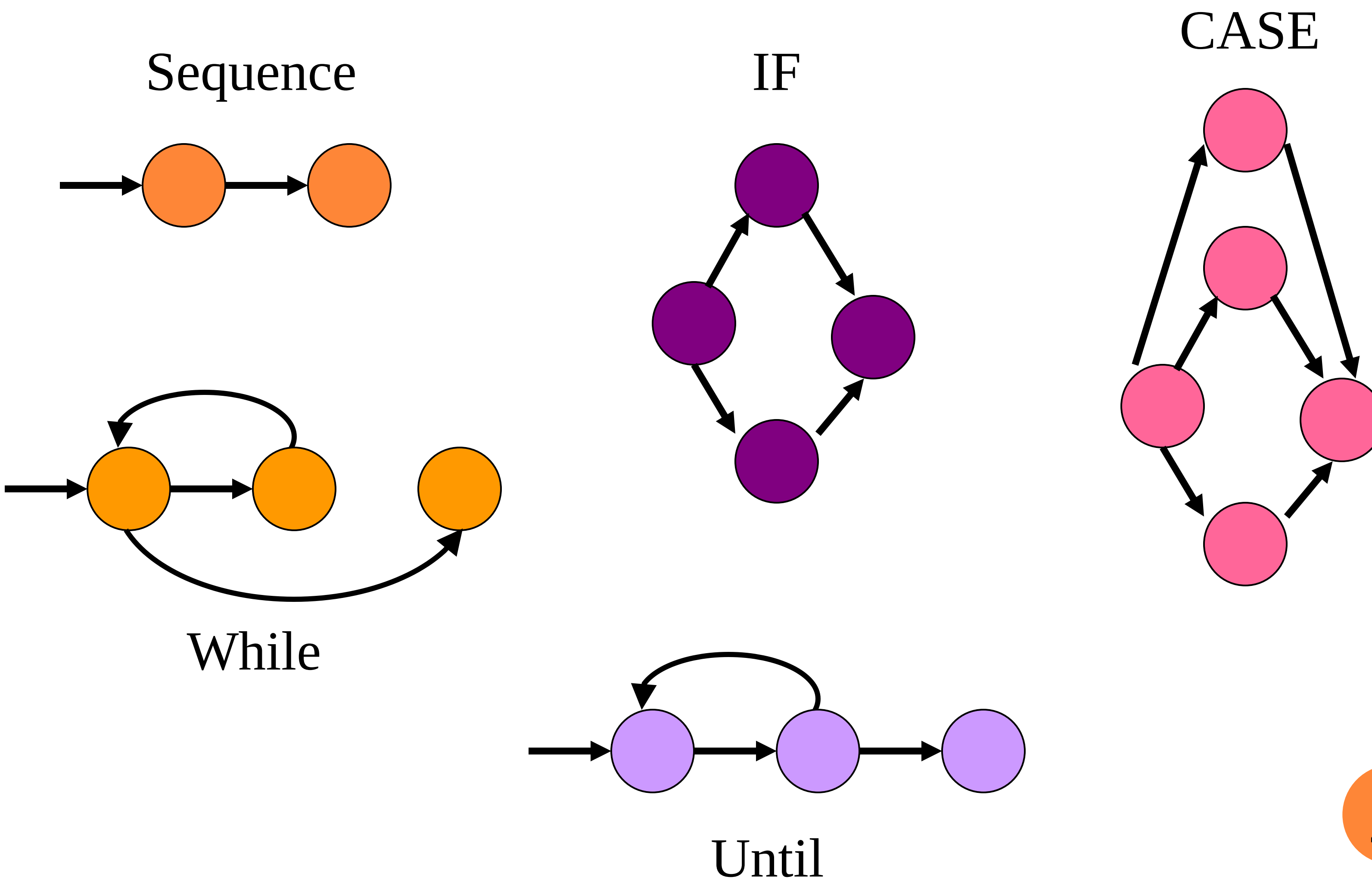
- Cyclomatic Complexity (V(G))
  - V(G) = the number of region of the flow graph + the area outside the graph
  - V(G) = E - N + 2

    where E = the number of flow graph edges

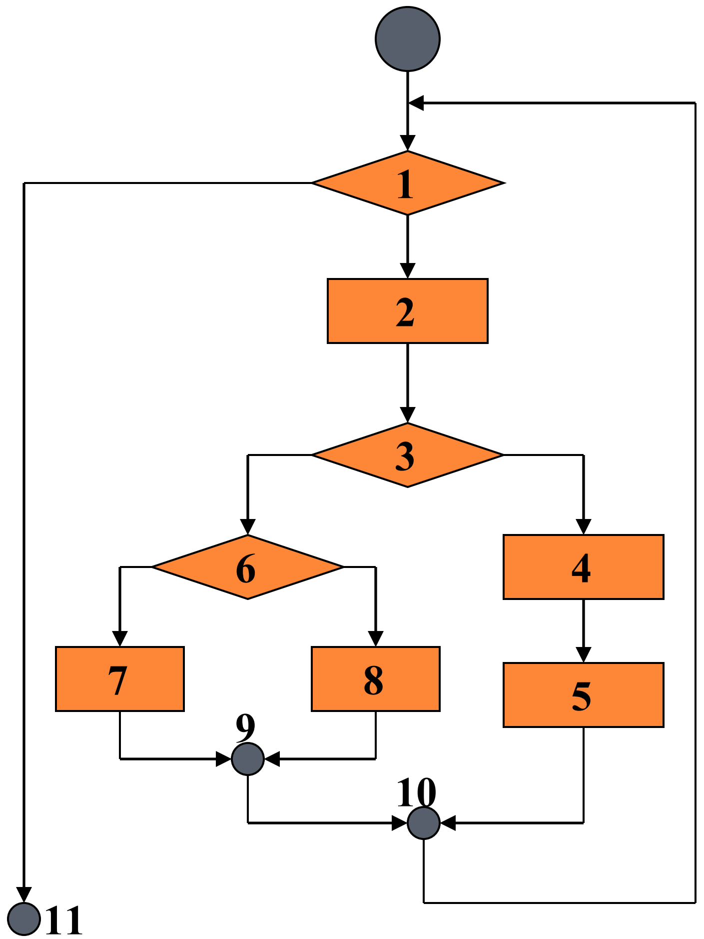
    N = the number of flow graph nodes
  - V(G) = P + 1

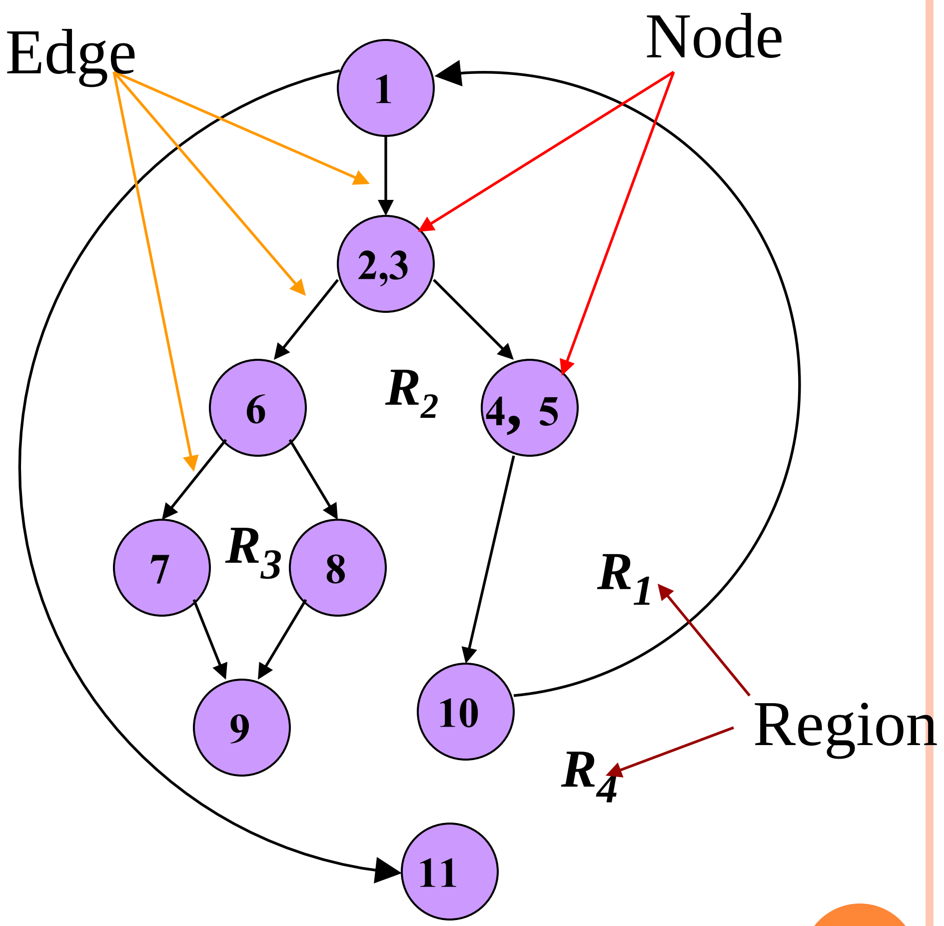
    where P = the number of predicate nodes

Flow Graph Notation



Cyclomatic Complexity - Example





METRICS FOR TESTING

- Size of the software
- High-level design metric
- Cyclomatic complexity

METRICS FOR MAINTENANCE

- Fix Backlog and Backlog Management Index
- Fix Response Time
- Percent Delinquent Fixes
- Fix Quality
- Software Maturity Index (SMI)

Fix Backlog and Backlog Management Index

- Fix backlog is a work load statement for software maintenance.
- It is a simple count of reported problems that remain opened at the end of each month or each week.
- Backlog management index (BMI)

$$BMI = \frac{\text{Number of problems closed during the month}}{\text{Number of problem arrivals during the month}} \times 100\%$$

FIX RESPONSE TIME

- Fix response time metric

  = Mean time of all problems from open to closed

PERCENT DELINQUENT FIXES

- For each fix, if the turnaround time exceeds the response time criteria by severity, then it is classified as delinquent
- Percent delinquent fixes =

$$\frac{\text{Number of fixes that exceeds the fix response time criteria by severity level}}{\text{Total number of fixes delivered in a specified time}} \times 100\%$$

Fix Quality

- Fix quality or the number of defective fixes metric = the percentage of all fixes in a time interval that are defective.
- A fix is defective if it did not fix the problem that was reported, or if it fixed the original problem but injected a new defect.
- A defective fix can be recorded in the month it was discovered or in the month when the fix was delivered.

Software Maturity Index (SMI)

- **$SMI = [M_T - (F_a + F_c + F_d)]/ M_T$**

  M_T = the number of modules in the current release

  F_c = the number of modules in the current release that have been changed

  F_a = the number of modules in the current release that have been added

  F_d = the number of modules from the preceding release that were deleted in the current release

Software Metrics Etiquette

- Use common sense and organizational sensitivity when interpreting metrics data.
- Provide regular feedback to the individuals and teams who have worked to collect measures and metrics.
- Don’t use metrics to appraise individuals
- Work with practitioners and teams to set clear goals and metrics that will be used to achieve them.
- Never use metrics to threaten individuals or teams.
- Metrics data that indicate a problem area should not be considered “negative”. These data are merely an indicator for process improvement.
- Don’t obsess on a single metric to the exclusion of other important metrics.