Short Overview of Software Product Lines

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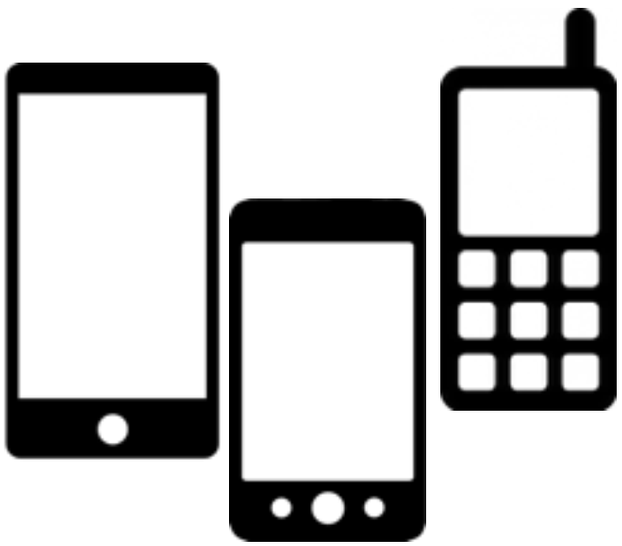
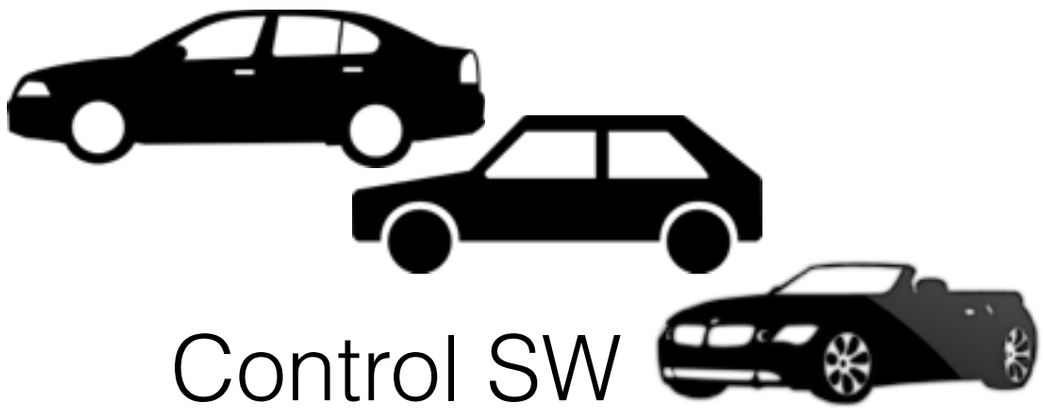
Examples of Software Product Lines



Mobile OS



Control SW

Printer Firmware

Linux Kernel

Software Product Lines

"A software product line (SPL) is a set of software-intensive systems that **share a common, managed set of features** satisfying the specific needs of a particular market segment or mission and that are **developed from a common set of core assets** in a prescribed way."

— Software Engineering Institute
Carnegie Mellon University

Advantages of SPLs

- Tailor-made software
- Reduced cost
- Improved quality
- Reduced time to market

Success Stories

Challenges of SPLs

- Upfront cost for preparing reusable parts
- Deciding which products you can produce early on
- Thinking about multiple products at the same time
- Managing/testing/analyzing multiple products

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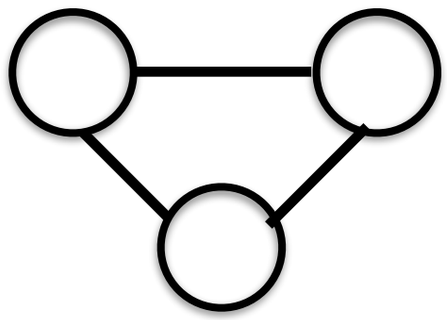
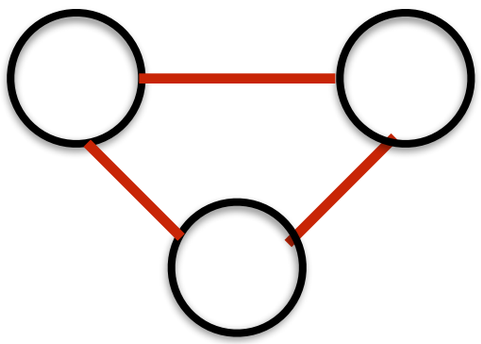
Feature-oriented SPLs

- Thinking of your product line in terms of the features offered

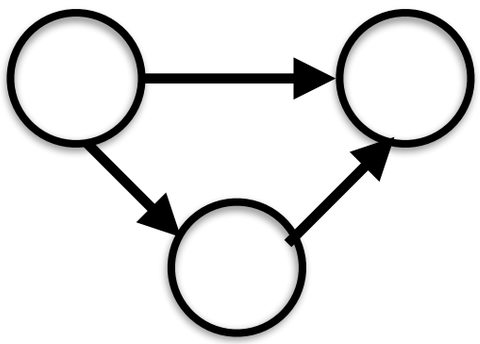
Examples of a Feature



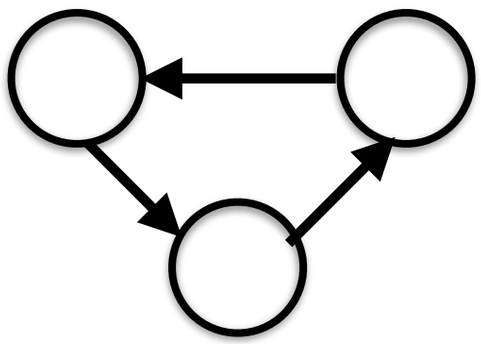
Graph product-line



feature:
edge color



feature:
edge type
(Directed vs Undirected)



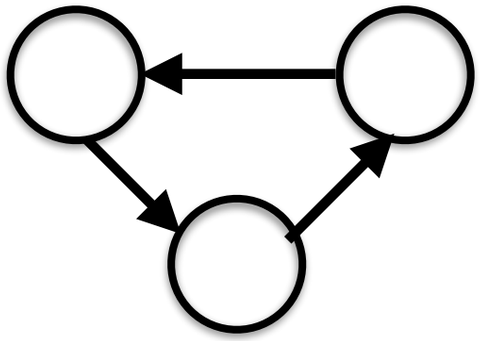
feature:
cycle detection

Feature

Definition 2.1 A *feature* is a characteristic or end-user-visible behavior of a software system. Features are used in product-line engineering to specify and communicate commonalities and differences of the products between stakeholders, and to guide structure, reuse, and variation across all phases of the software life cycle. □

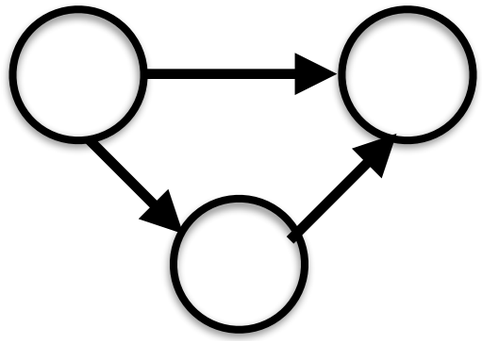
Feature Dependencies

- Constraints on the possible feature selections



feature:
cycle detection

depends on



feature:
directed

Product

Definition 2.2 A *product* of a product line is specified by a valid feature selection (a subset of the features of the product line). A feature selection is *valid* if and only if it fulfills all *feature dependencies*. □

Which Product(s) are Invalid?

	Edge Color	Directed Edge	Cycle Detection
Product 1	✓	✓	✓
Product 2	✓		✓
Product 3		✓	✓

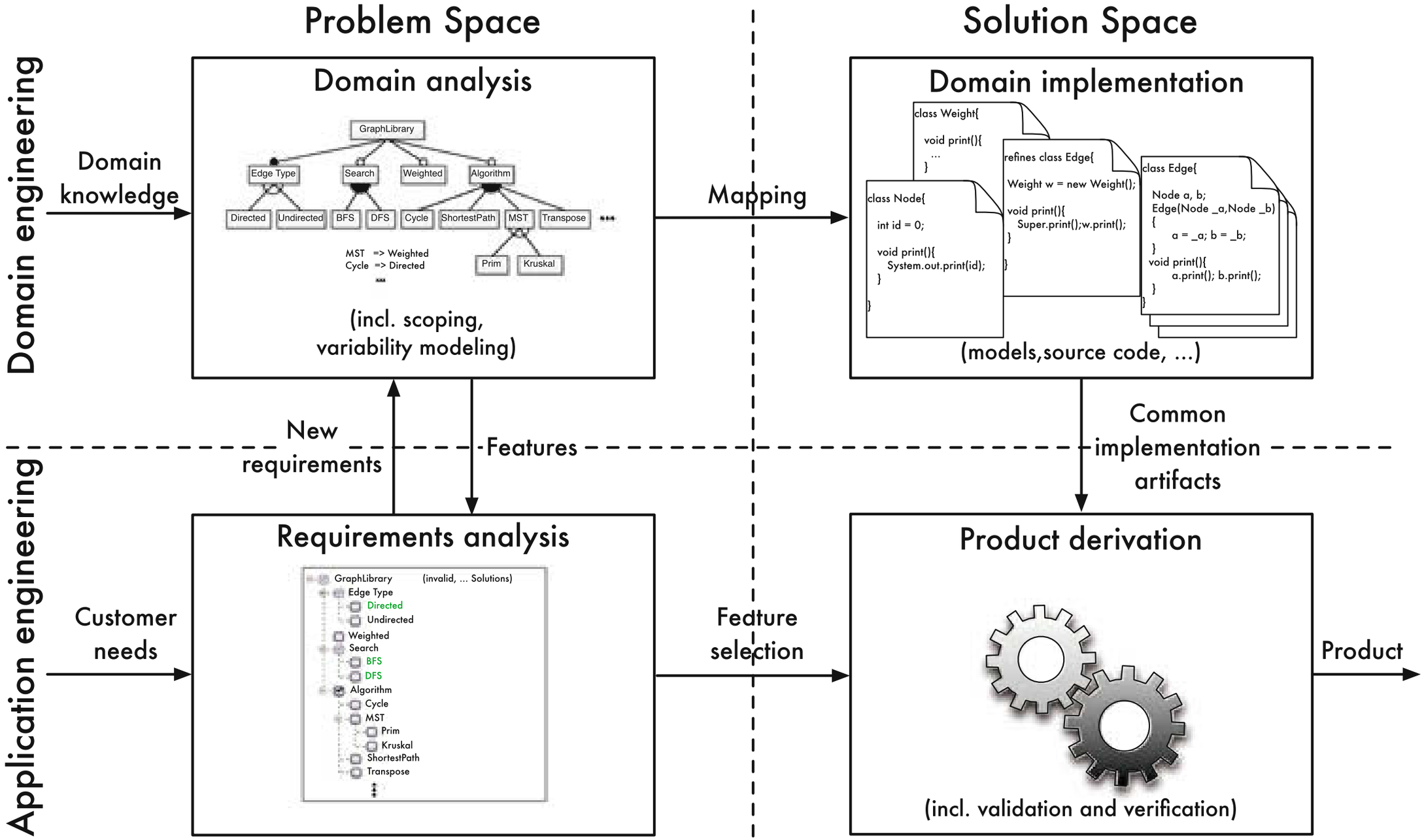
Which Product(s) are Invalid?

	Edge Color	Directed Edge	Cycle Detection
Product 1	✓	✓	✓
Product 2	✓		✓
Product 3		✓	✓

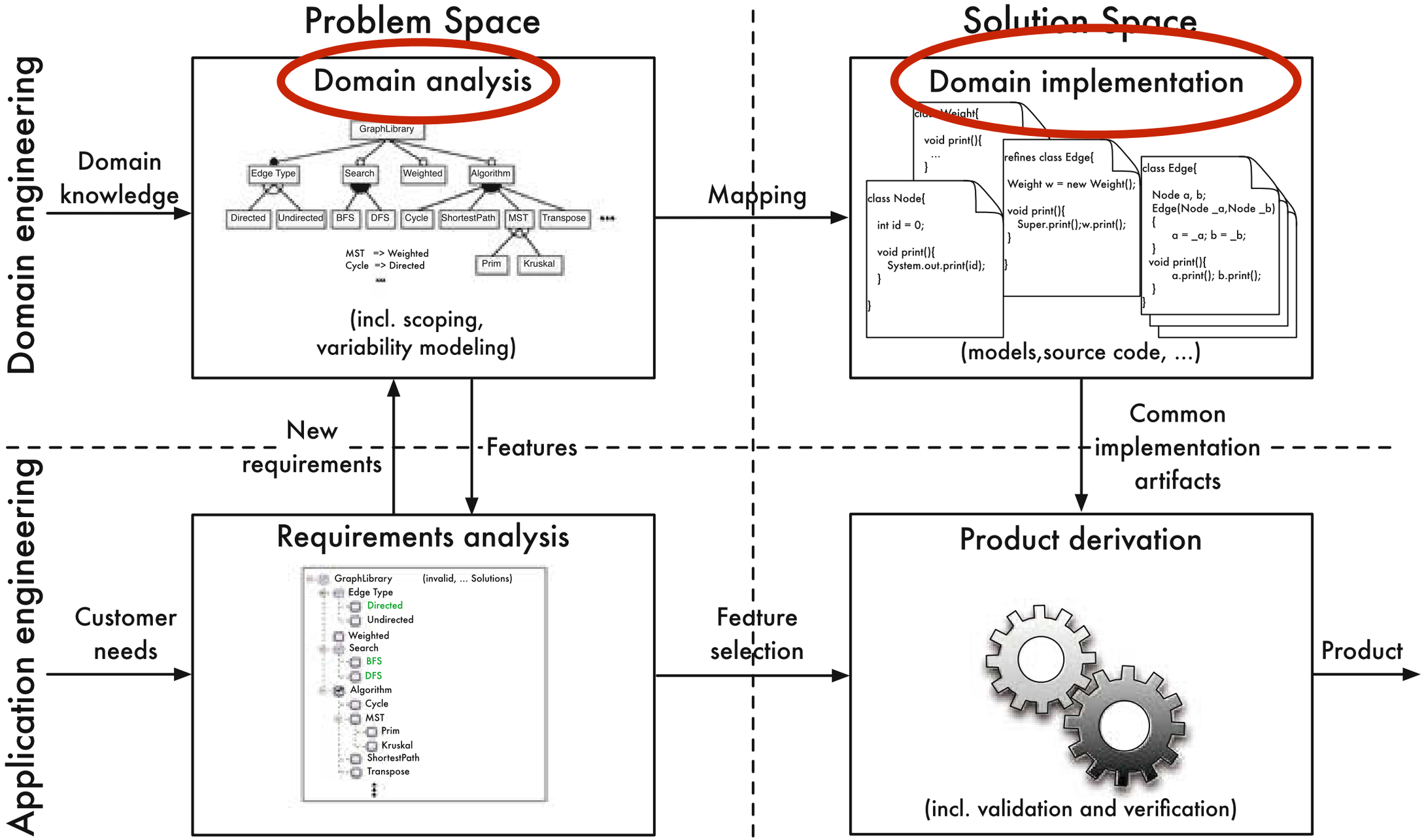
invalid product

Cycle detection depends on Directed Edge

Software Product Line Engineering



Software Product Line Engineering



Domain Analysis

Domain Analysis

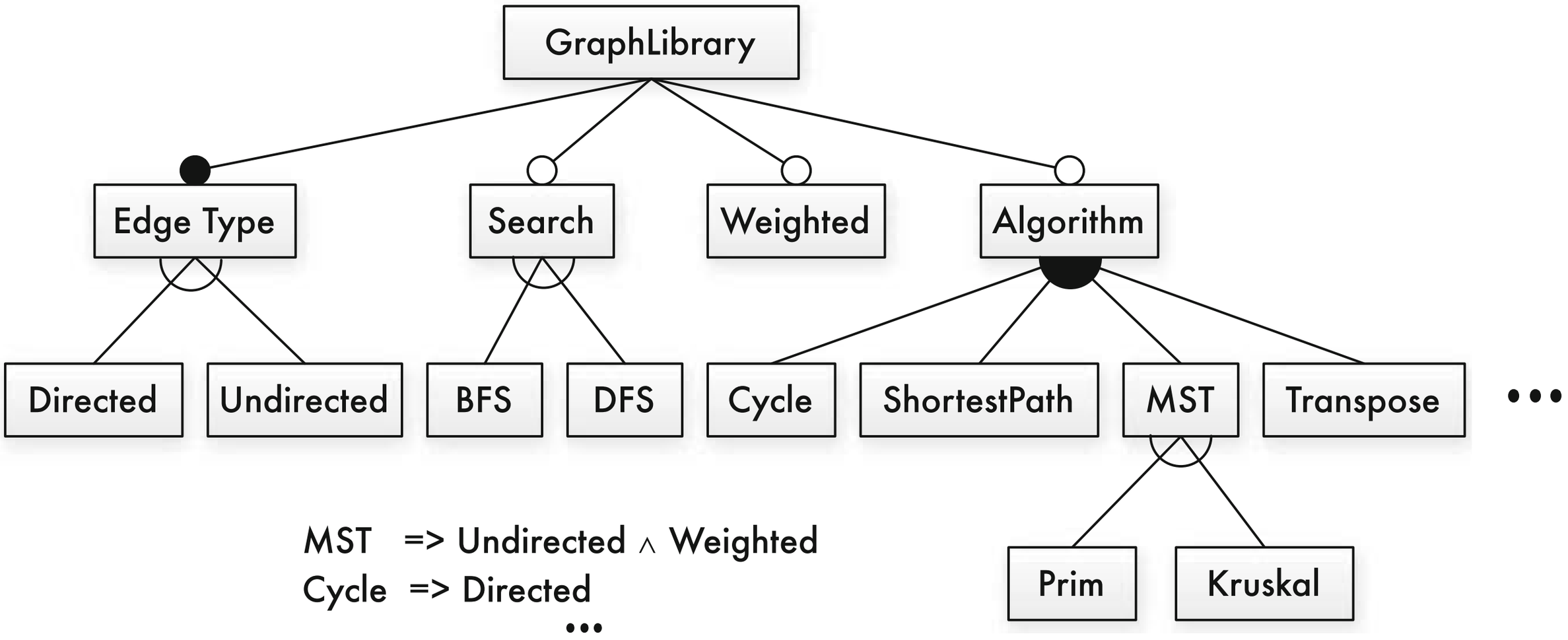
- Domain scoping
  - Deciding on product line's extent or range
- Domain modeling
  - Captures & documents the commonalities & variabilities of the scoped domain
  - Often captured in a *feature model*

Feature Models

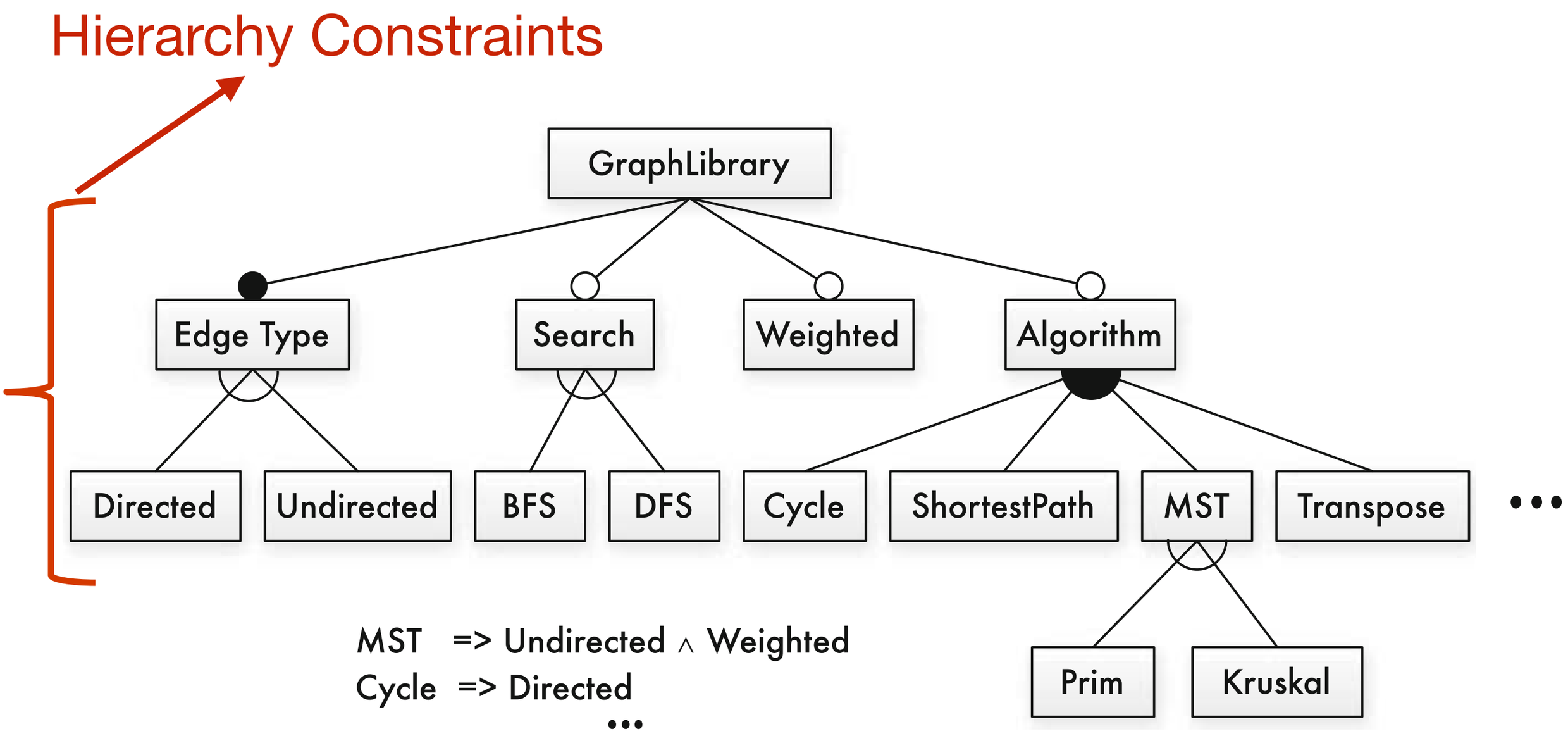
- Document the features of a product line & their relationships

- Can be translated into propositional logic

Graph Library Feature Model

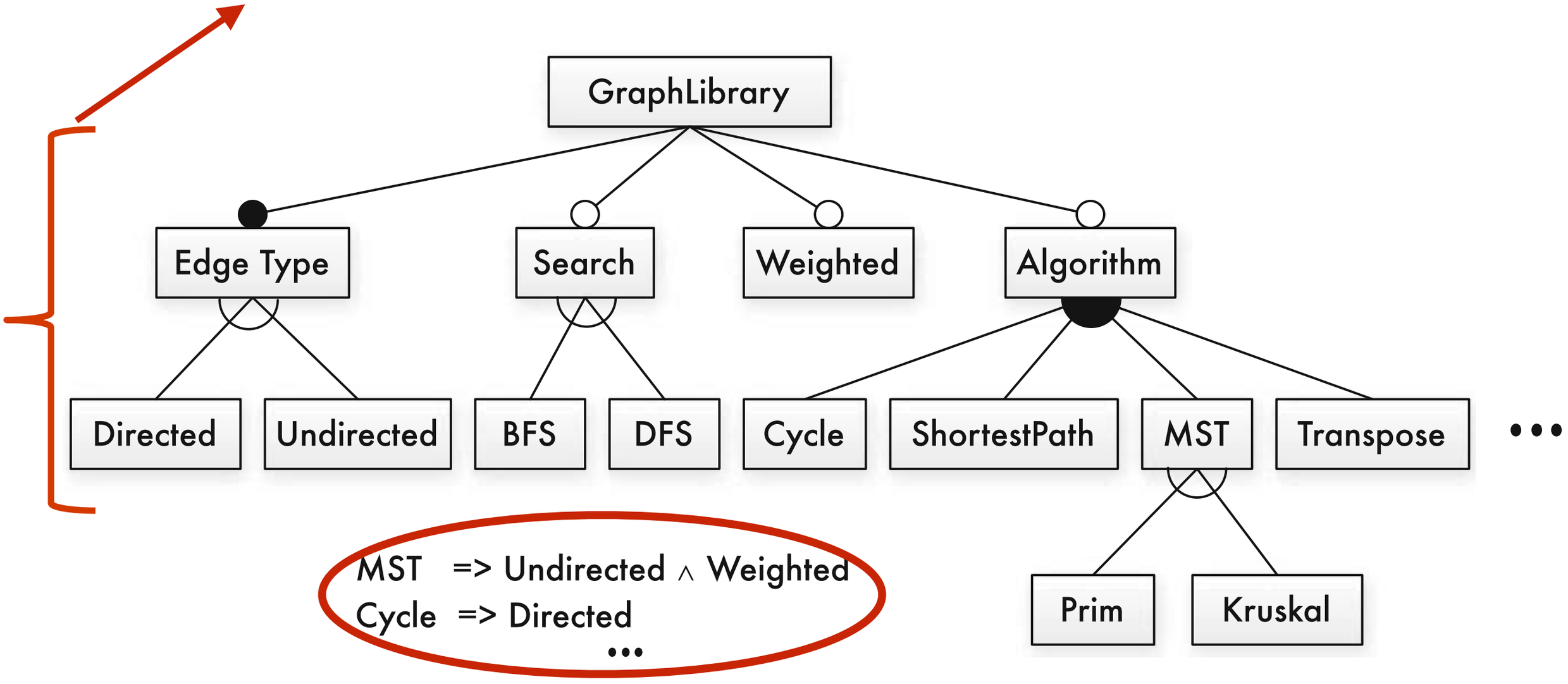


Graph Library Feature Model



Graph Library Feature Model

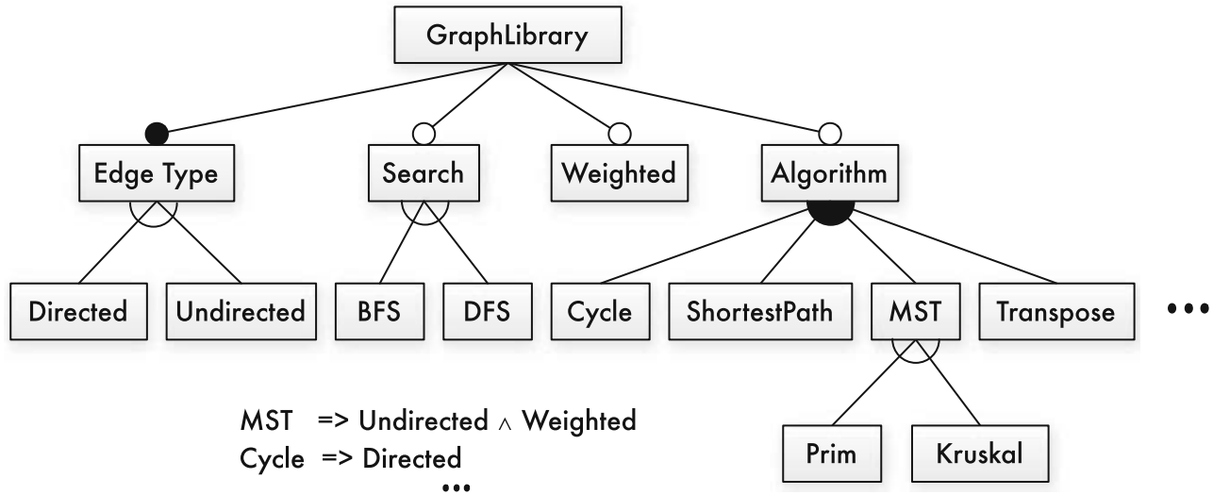
Hierarchy Constraints



Cross-tree Constraints

Feature Model in Propositional Logic

$$
\begin{aligned}
&\texttt{GraphLibrary} \\
&\wedge\ (\texttt{EdgeType} \Leftrightarrow \texttt{GraphLibrary}) \\
&\wedge\ (\texttt{Search} \Rightarrow \texttt{EdgeType}) \\
&\wedge\ (\texttt{Weighted} \Rightarrow \texttt{EdgeType}) \\
&\wedge\ (\texttt{Algorithm} \Rightarrow \texttt{EdgeType}) \\
&\wedge\ (((\texttt{Directed} \vee \texttt{Undirected}) \Leftrightarrow \texttt{EdgeType}) \wedge \neg(\texttt{Directed} \wedge \texttt{Undirected})) \\
&\wedge\ ((\texttt{BFS} \vee \texttt{DFS}) \Leftrightarrow \texttt{Search}) \\
&\wedge\ ((\texttt{Cycle} \vee \texttt{ShortestPath} \vee \texttt{MST} \vee \texttt{Transpose}) \Leftrightarrow \texttt{Algorithm}) \\
&\wedge\ (((\texttt{Prim} \vee \texttt{Kruskal}) \Leftrightarrow \texttt{MST}) \wedge \neg(\texttt{Prim} \wedge \texttt{Kruskal})) \\
&\wedge\ (\texttt{MST} \Rightarrow \texttt{Weighted}) \\
&\wedge\ (\texttt{Cycle} \Rightarrow \texttt{Directed}) \\
&\wedge\ (\cdots)
\end{aligned}
$$

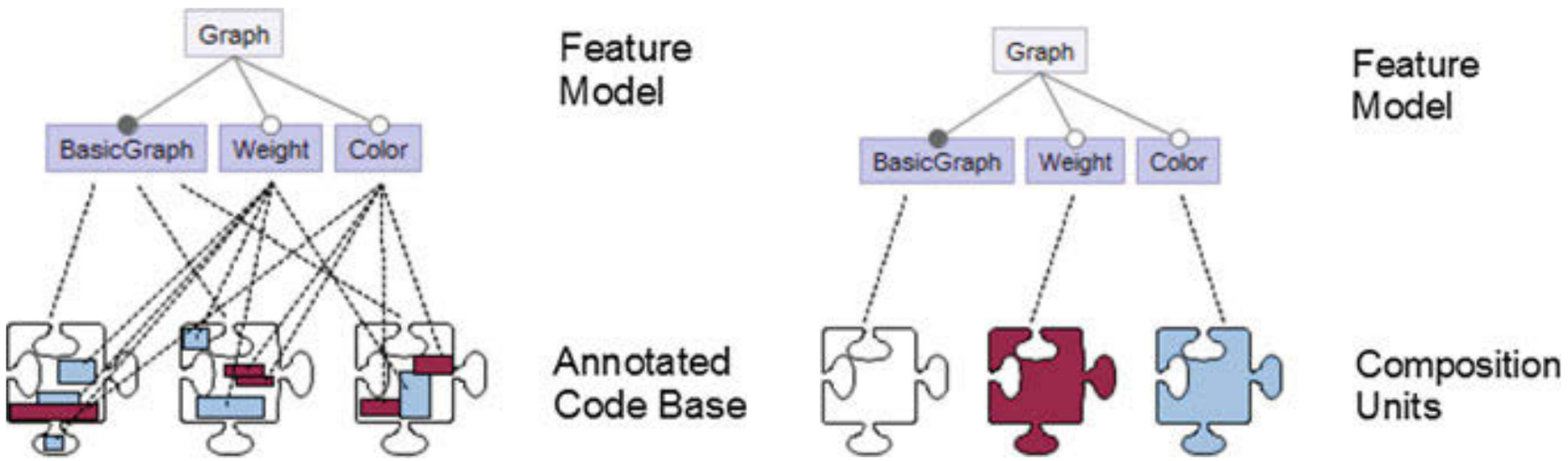


Domain

Implementation

Domain Implementation

- Underlying code must be *variable*
- Dimensions of implementation techniques
  - *Binding times:* compile-time binding, load-time binding, and run-time binding.
- *Representation:* annotation vs composition



(a) Annotation-based approach **(b)** Composition-based approach

Variability Implementation

- Parameters
- Build systems
- Preprocessors
- …

Working Example: Basic Graph Library (Java)

```
1  class Graph {
2    Vector nodes = new Vector():
3    Vector edges = new Vector();
4    Edge add(Node n, Node m) {
5      Edge e = new Edge(n,m);
6      nodes.add(n);
7      nodes.add(m);
8      edges.add(e);
9      return e;
10   }
11   void print() {
12     for(int i=0; i<edges.size(); i++){
13       ((Edge) edges.get(i)).print();
14       if(i < edges.size() - 1)
15         System.out.print(" , ");
16     }
17   }
18 }
```

```
19 class Node {
20   int id = 0;
21   Node (int _id) { id = _id; }
22   void print() {System.out.print(id);}
23 }
24
25
26 class Edge {
27   Node a, b;
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29   void print() {
30     System.out.print(" (");
31     a.print();
32     System.out.print(" , ");
33     b.print();
34     System.out.print(") ");
35   }
36 }
```

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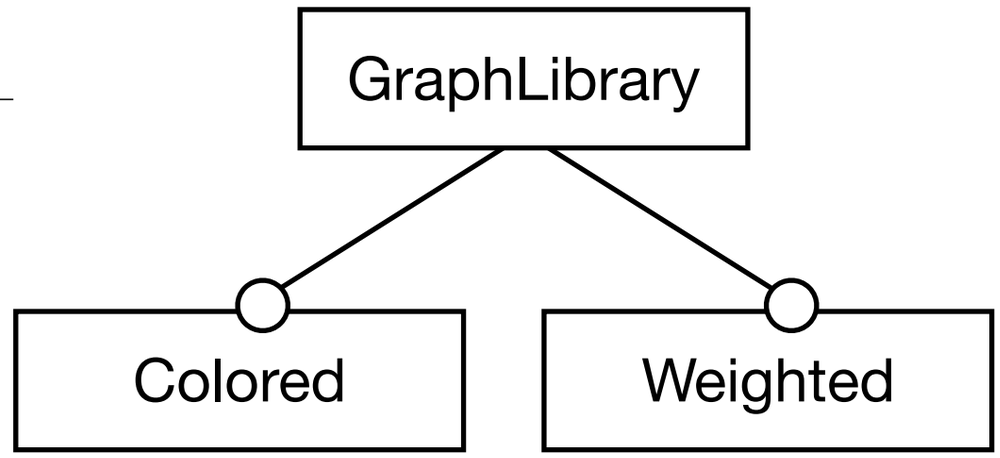

Parameters

Variability using Parameters

```
1  class Conf {
2    public static boolean COLORED = true;
3    public static boolean WEIGHTED = false;
4  }
5
6
7  class Graph {
8    Vector nodes = new Vector();
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10   Edge add(Node n, Node m) {
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15     if (Conf.WEIGHTED)
16       e.weight = new Weight();
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19   Edge add(Node n, Node m, Weight w) {
20     if (!Conf.WEIGHTED)
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68   static void setDisplayColor(Color c)...
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70 class Weight {
71   void print() { ... }
72 }
```

Build Systems

Variability Using Build Scripts

```
1  #!/bin/bash -e
2
3  rm *.class
4  javac Graph.java Edge.java Node.java \
5        Color.java
6  jar cvf graph.jar *.class
```

No variability

```
1  #!/bin/bash -e
2
3  if test "$1" = "--withColor"; then
4    cp Edge_withColor.java Edge.java
5    cp Node_withColor.java Node.java
6  else
7    cp Edge_withoutColor.java Edge.java
8    cp Node_withoutColor.java Node.java
9  fi
10
11 rm *.class
12 javac Graph.java Edge.java Node.java
13 if test "$1" = "--withColor"; then
14   javac Color.java
15 fi
16
17 jar cvf graph.jar *.class
```

With variability

Variability Using Build Scripts

```
1  #!/bin/bash -e
2
3  rm *.class
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No variability

```
1  #!/bin/bash -e
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9  fi
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12 javac Graph.java Edge.java Node.java
13 if test "$1" = "--withColor"; then
14   javac Color.java
15 fi
16
17 jar cvf graph.jar *.class
```

With variability

Preprocessors

Variability Using Preprocessors

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3    Vector edges = new Vector();
4    Edge add(Node n, Node m) {
5      Edge e = new Edge(n,m);
6      nodes.add(n);
7      nodes.add(m);
8      edges.add(e);
9      /*IF[FEAT_WEIGHTED]*/
10     e.weight = new Weight();
11     /*END[FEAT_WEIGHTED]*/
12     return e;
13   }
14   /*IF[FEAT_WEIGHTED]*/
15   Edge add(Node n, Node m, Weight w) {
16     Edge e = new Edge(n, m);
17     e.weight = w;
18     nodes.add(n);
19     nodes.add(m);
20     edges.add(e);
21     return e;
22   }
23   /*END[FEAT_WEIGHTED]*/
24   void print() {
25     for(int i=0; i<edges.size(); i++){
26       ((Edge) edges.get(i)).print();
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30   }
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33
34 /*IF[FEAT_COLORED]*/
35 class Color {
36   static void setDisplayColor(Color c)...
37 }
38 /*END[FEAT_COLORED]*/
```

```
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42   Color color = new Color();
43   /*END[FEAT_COLORED]*/
44   Node (int _id) { id = _id; }
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56   Color color = new Color();
57   /*END[FEAT_COLORED]*/
58   /*IF[FEAT_WEIGHTED]*/
59   Weight weight;
60   /*END[FEAT_WEIGHTED]*/
61   Edge(Node _a, Node _b) {a=_a; b=_b;}
62   void print() {
63     /*IF[FEAT_COLORED]*/
64     Color.setDisplayColor(color);
65     /*END[FEAT_COLORED]*/
66     System.out.print(" (");
67     a.print();
68     System.out.print(" , ");
69     b.print();
70     System.out.print(") ");
71     /*IF[FEAT_WEIGHTED]*/
72     weight.print();
73     /*END[FEAT_WEIGHTED]*/
74   }
75 }
76
77 /*IF[FEAT_WEIGHTED]*/
78 class Weight {
79   void print() { ... }
80 }
81 /*END[FEAT_WEIGHTED]*/
```

Variability using the C Preprocessor

Can you spot the error?

```
1  int a = 1;
2  int b = 0;
3  #ifdef A
4  int c = a;
5  #else
6  char c = a;
7  #endif
8  if (c) {
9  #ifdef B
10   c += a;
11   c /= b;
12 }
13 #endif
```

Variability using the C Preprocessor

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```

Compile time: no matching closing braces when B is not selected

Variability using the C Preprocessor

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10   c += a;
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12 }
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```

Compile time: no matching closing braces when B is not selected

Runtime: division by zero when B is selected

Sample Research Topics

Detecting Inconsistencies

```
PCCARD => HOTPLUG
PCMCIA => PCCARD
```

Feature Model

```
#ifdef HOTPLUG
//B1
#else
//B2
#endif
```

ds.c
Code

```
ds.c <=> PCMCIA
```

Build Files

[Nadi & Holt: CSMR ’12]

Detecting Inconsistencies

3 `PCCARD => HOTPLUG`
4 `PCMCIA => PCCARD`

Feature Model

```
#ifdef HOTPLUG
//B1
#else
//B2
#endif
```
1

ds.c
Code

2 `ds.c <=> PCMCIA`

Build Files

```
B2 ∧
1 B2 <=> !HOTPLUG ∧
2 PCMCIA ∧
3 PCMCIA => PCCARD ∧
4 PCCARD => HOTPLUG
```

[Nadi & Holt: CSMR ’12]

Detecting Inconsistencies

3 PCCARD => HOTPLUG
4 PCMCIA => PCCARD

Feature Model

```
#ifdef HOTPLUG
//B1
#else
//B2
#endif
```

1

ds.c
Code

2 ds.c <=> PCMCIA

Build Files

```
B2 ∧
1 B2 <=> !HOTPLUG ∧
2 PCMCIA ∧
3 PCMCIA => PCCARD ∧
4 PCCARD => HOTPLUG
```

[Nadi & Holt: CSMR ’12]

Detecting Inconsistencies

3 PCCARD => HOTPLUG
4 PCMCIA => PCCARD

Feature Model

```
#ifdef HOTPLUG
//B1
#else
//B2
#endif
```

1

ds.c
Code

2 ds.c <=> PCMCIA

Build Files

```
B2 ∧
1 B2 <=> !HOTPLUG ∧
2 PCMCIA ∧
3 PCMCIA => PCCARD ∧
4 PCCARD => HOTPLUG
```

B2 is dead

[Nadi & Holt: CSMR ’12]

Detecting Configuration Constraints

```
#ifdef SHAPE
  static shape *myshape;
#endif

int main(){
  #ifdef AREA
    double area = myshape-> area;
  #endif
}
```

[Nadi et al.: ICSE ‘14]

Detecting Configuration Constraints

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[Nadi et al.: ICSE ‘14]

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Type error if
AREA ∧ !SHAPE

[Nadi et al.: ICSE ‘14]

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Type error if
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Feature model should enforce !(AREA ∧ !SHAPE)

[Nadi et al.: ICSE ‘14]

Detecting Configuration Constraints

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  #endif
}
```

Type error if
AREA ∧ !SHAPE

Constraint:
AREA => SHAPE

Feature model should enforce !(AREA ∧ !SHAPE)

[Nadi et al.: ICSE ‘14]

Detecting Configuration Constraints (Underlying Analysis)

```
#include <stdio.h>

#ifdef WORLD
char * msg = “Hello World”;
#endif

#ifdef BYE
char * msg = “Bye bye!\n”;
#endif

main() {
  print(msg);
}
```


[Kästner et al.: OOPSLA ‘11]

Detecting Configuration Constraints (Underlying Analysis)

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#include <stdio.h>

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char * msg = “Hello World”;
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main() {
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```
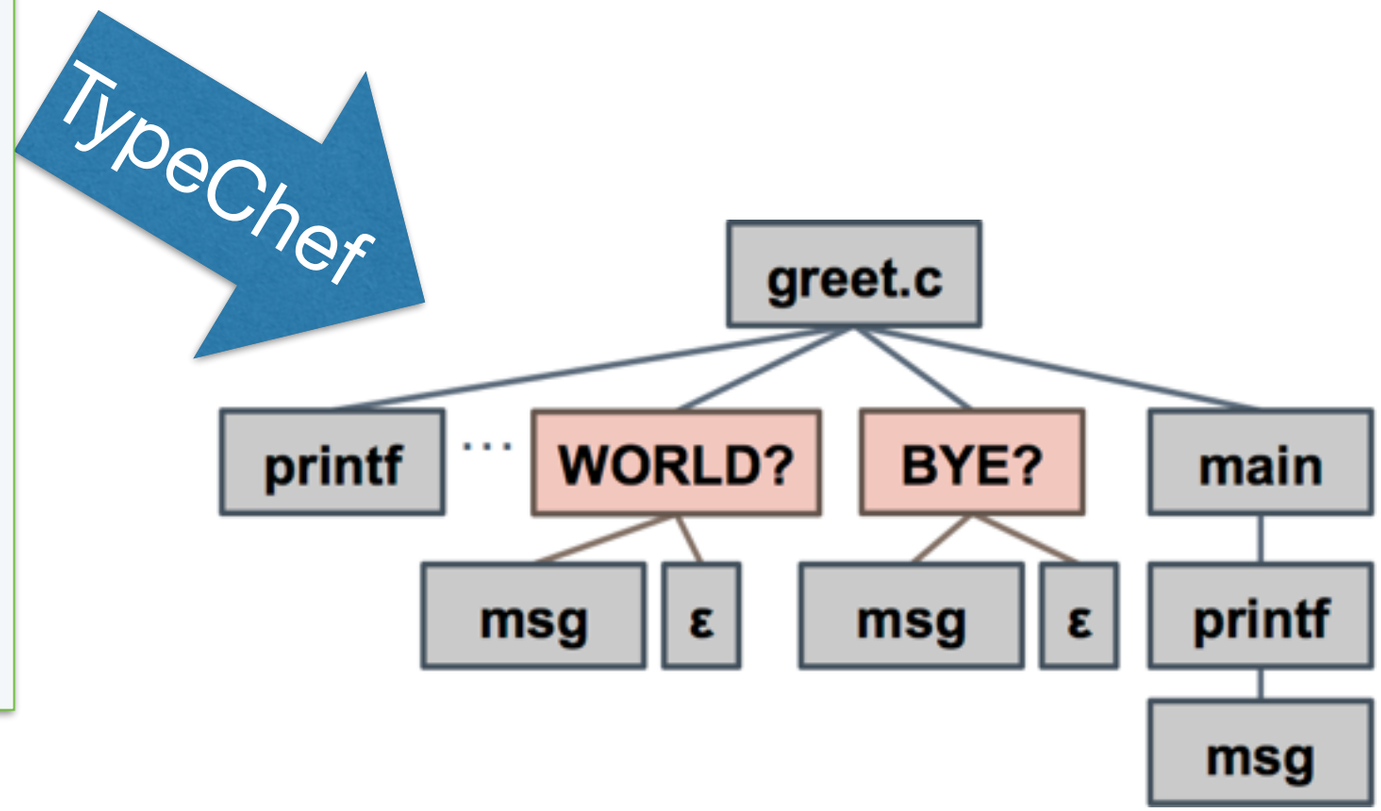

https://github.com/ckaestne/TypeChef



AST with variability information

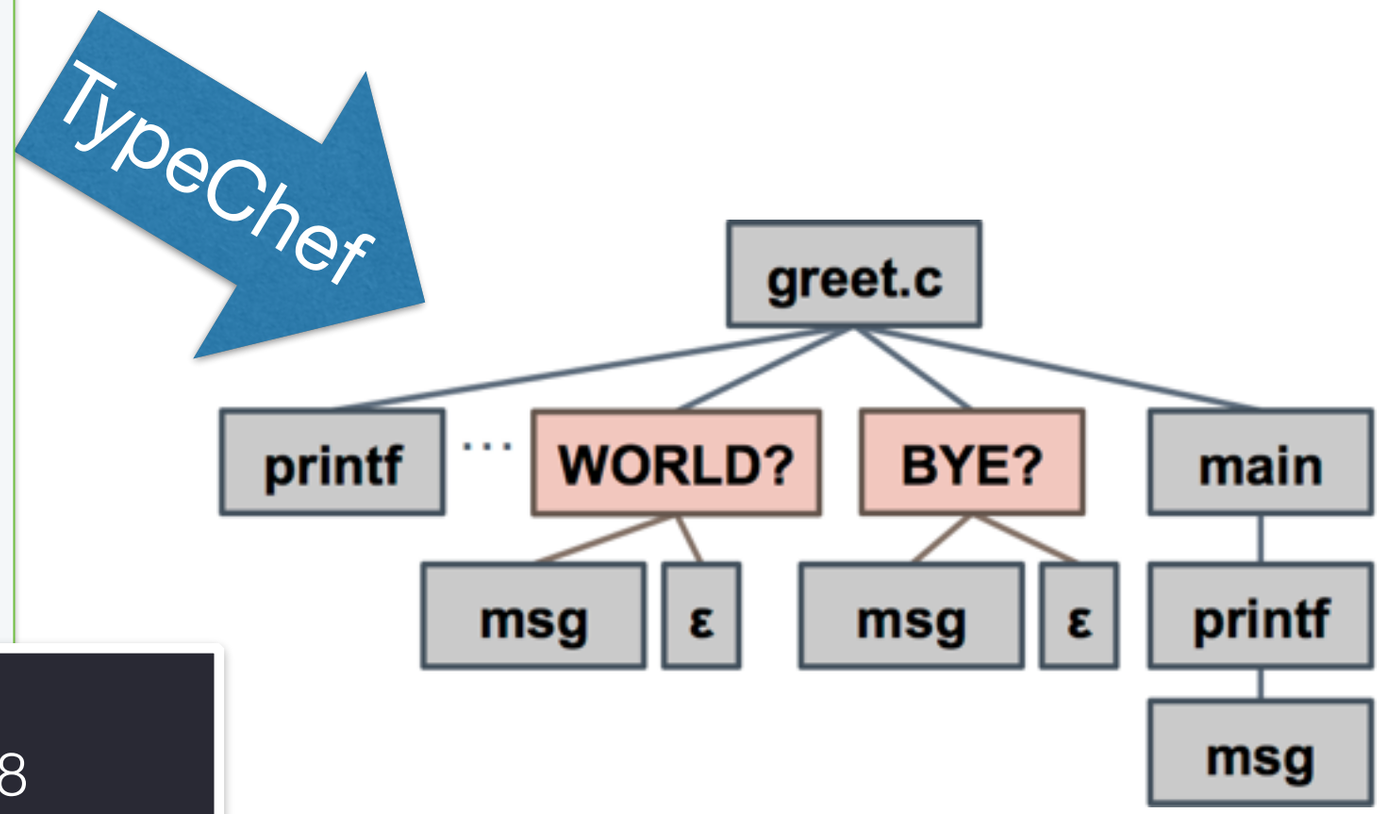
[Kästner et al.: OOPSLA ‘11]

Detecting Configuration Constraints (Underlying Analysis)

https://github.com/ckaestne/TypeChef

```
#include <stdio.h>

#ifdef WORLD
char * msg = “Hello World”;
#endif

#ifdef BYE
char * msg = “Bye bye!\n”;
#endif

main() {
  print(msg);
}
```

```
Found 2 type errors:
 - [WORLD & BYE] file greet.c:7:8
       redefinition of msg
 - [!WORLD & !BYE] file greet.c:11:8
       msg undeclared
```



AST with variability information

[Kästner et al.: OOPSLA ‘11]

Feature Interactions

Weather

Smiley

[Nguyen et al., ICSE ’14]

Feature Interactions

Weather

Smiley

Weather Updates:

Mostly cloudy today. It’s currently 20°C

[Nguyen et al., ICSE ’14]

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[Nguyen et al., ICSE '14]

Feature Interactions

Weather

Smiley

Weather Updates:

Mostly cloudy today. It's currently 20°C

Weather

Smiley

Weather Updates:

Mostly cloudy today. It's currently [:Temperature 

[Nguyen et al., ICSE '14]

Feature Interactions

Weather

Smiley

Weather

Smiley

Weather Updates:

Mostly cloudy today. It's currently 20°C

Temperature not displaying properly

Weather Updates:

Mostly cloudy today. It's currently [:Temperature

[Nguyen et al., ICSE '14]

Feature Interactions

Weather

Smiley

Weather

Smiley

Weather Updates:

Mostly cloudy today. It's currently 20°C

Temperature not displaying properly

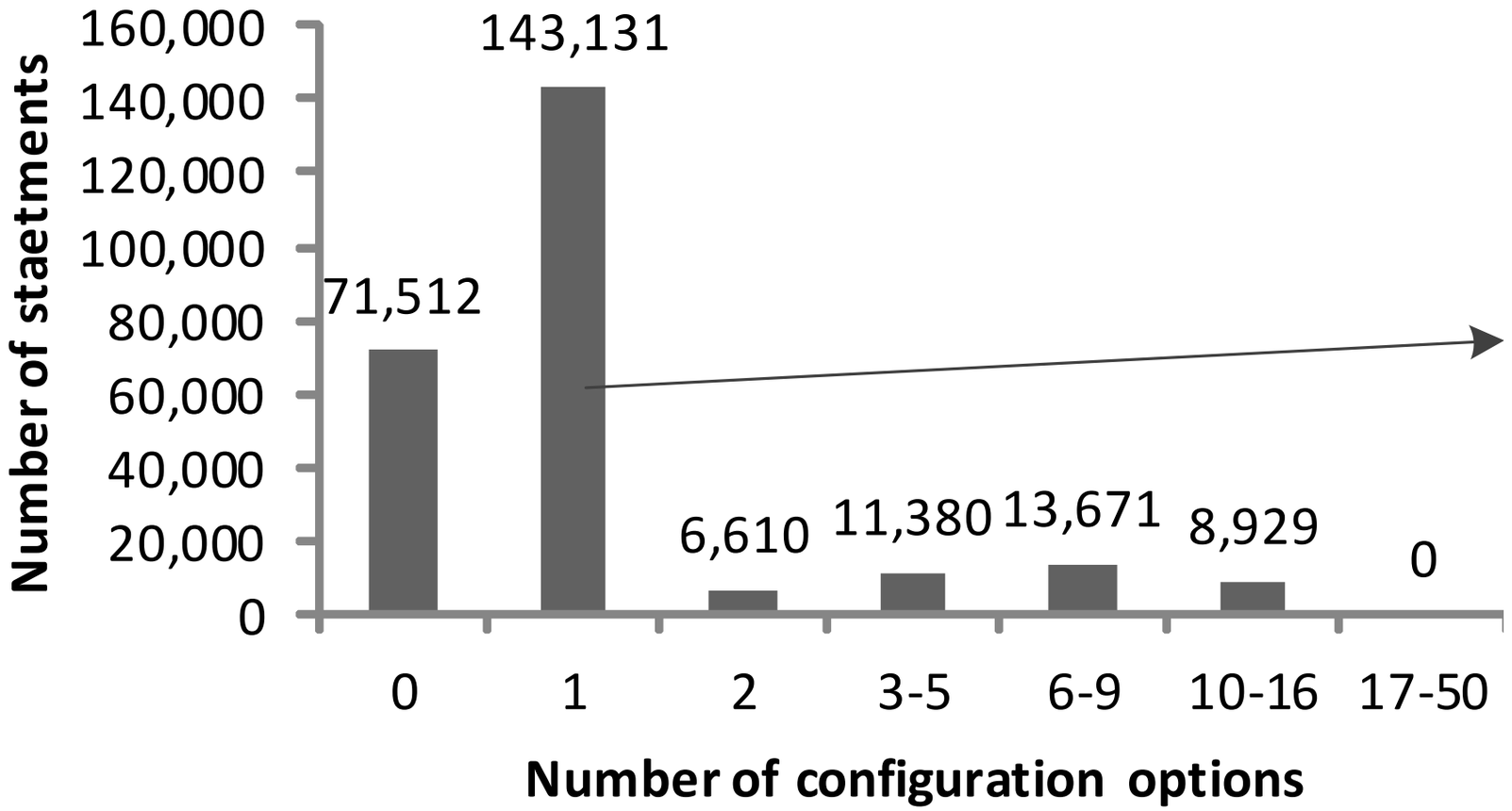
Weather Updates:

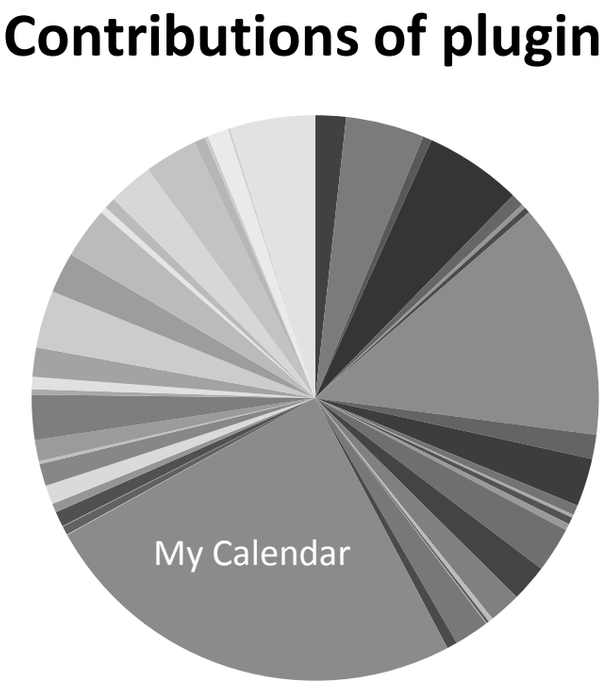
Mostly cloudy today. It's currently [:Temperature

Weather replaces [:Temperature:] with value while Smiley replaces :] with a smiley face

[Nguyen et al., ICSE '14]

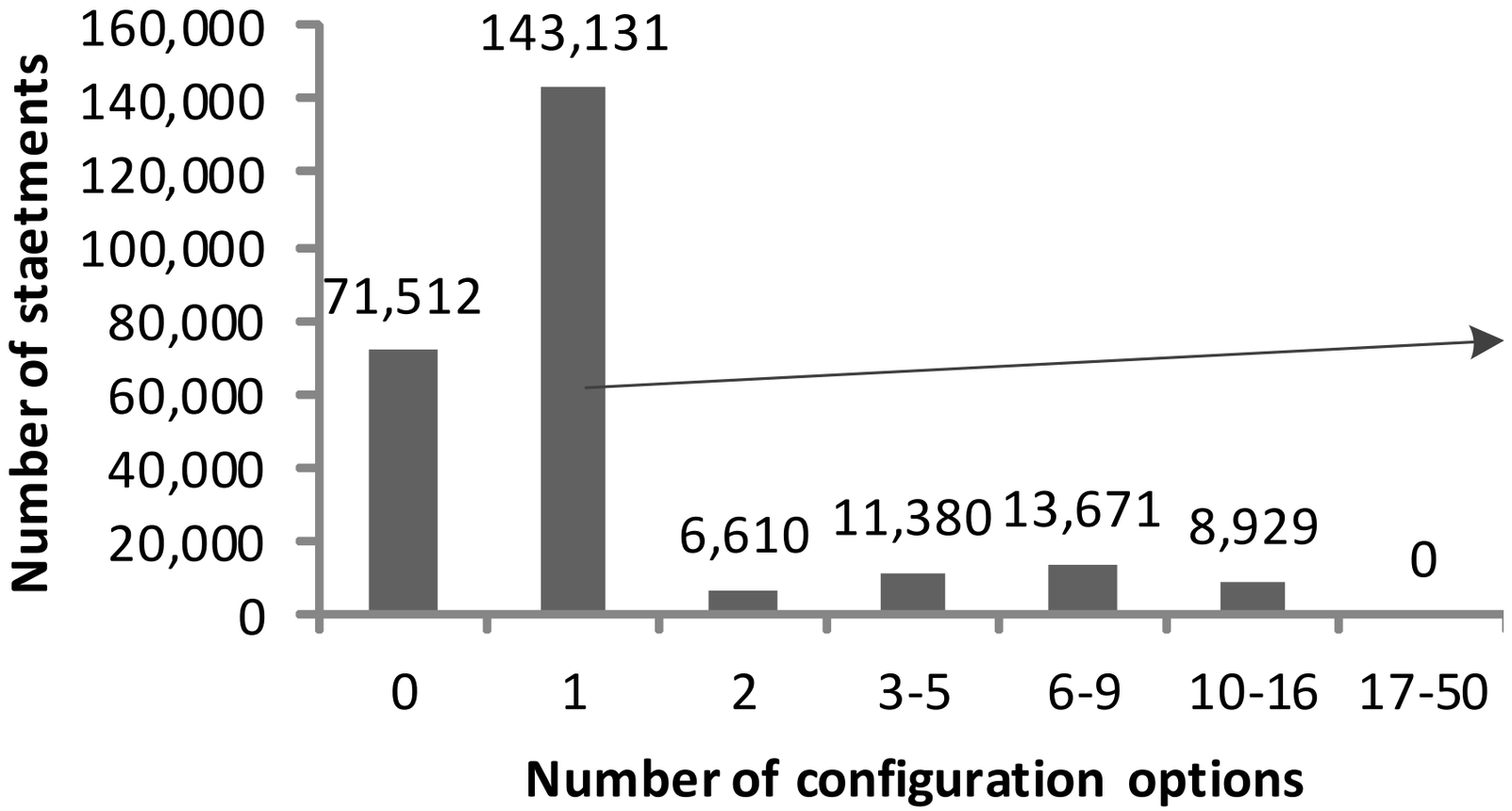
Detecting Feature Interactions

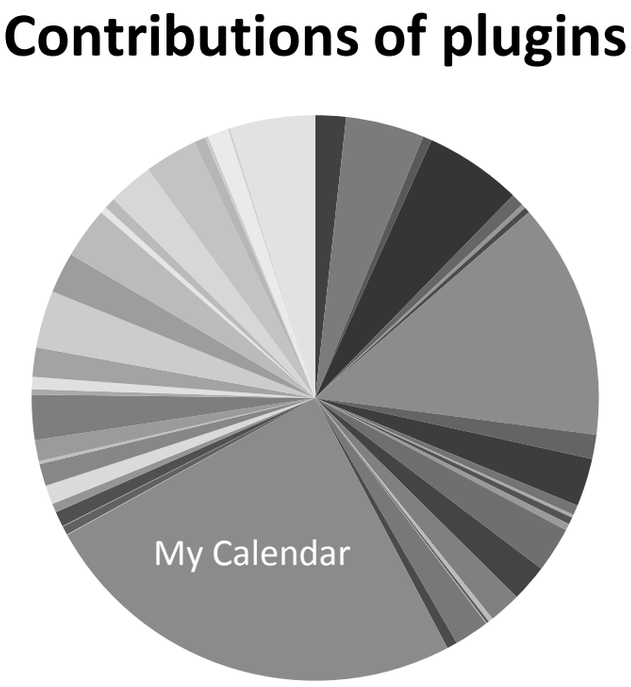




[Nguyen et al., ICSE '14]

Detecting Feature Interactions





Intended vs Unintended?

[Nguyen et al., ICSE '14]

Possible Project Topics

- Heuristics to detect *unintended* feature interactions
- Features vs options: nature of configurability in the Linux kernel
- Variability-aware refactoring during SPL migration
- Better code and/or build system comparison tools to identify commonality/variability?
- Does variability modeling of plug-in build dependencies provide any advantage?

Short Overview of Software Product Lines

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References

- Slides based on: