MACHINE LEARNING FOR SOFTWARE MAINTAINABILITY

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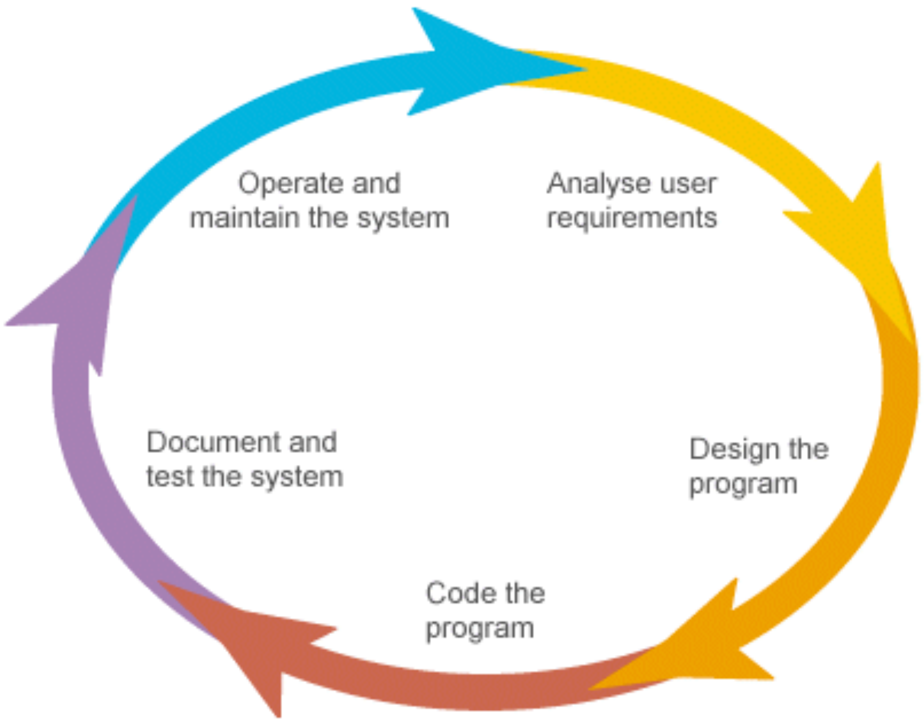
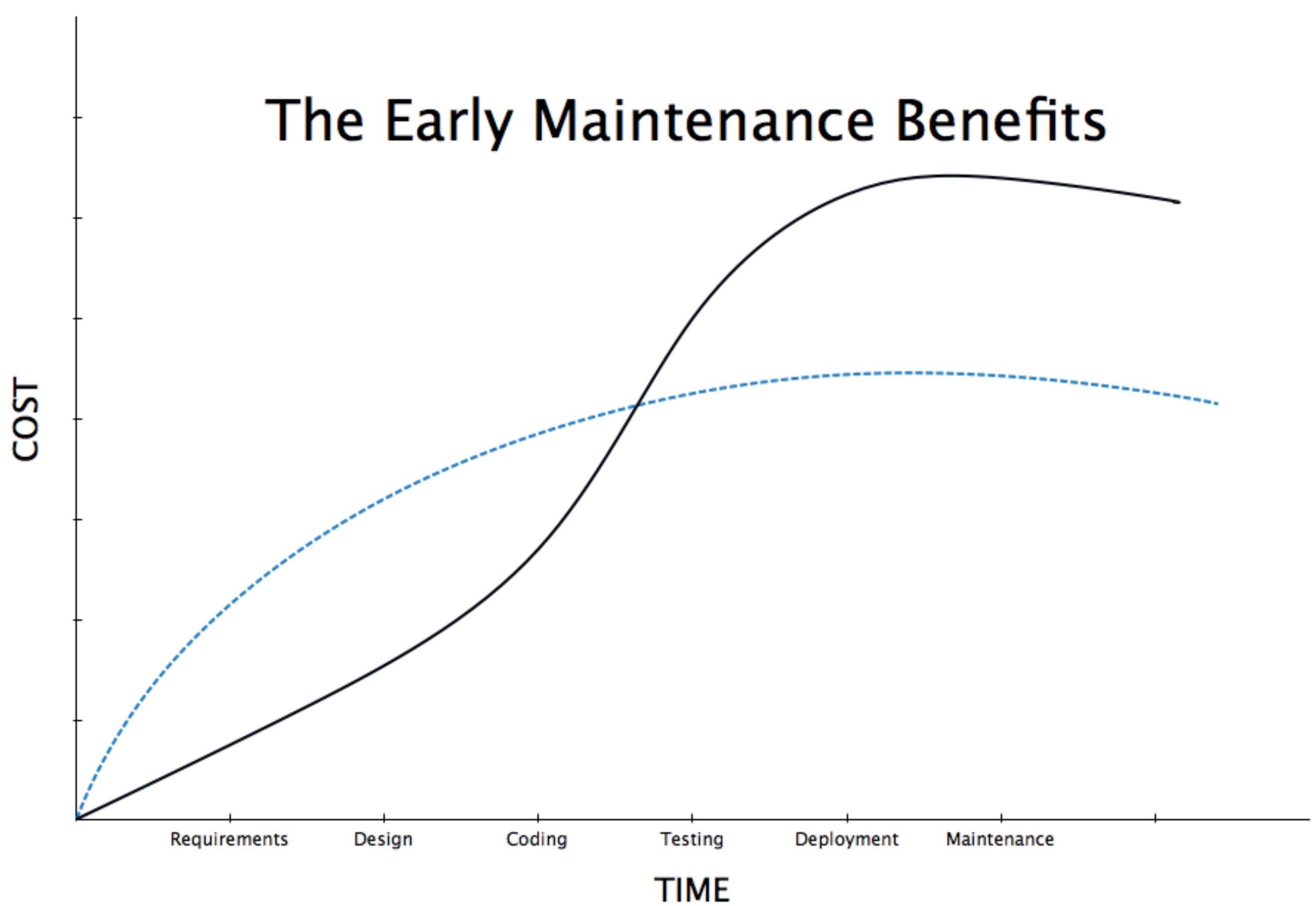
SOFTWARE MAINTENANCE

"A software system must be continuously adapted during its overall life cycle or it progressively becomes less satisfactory"
(cit. Lehman's Law of Software Evolution)

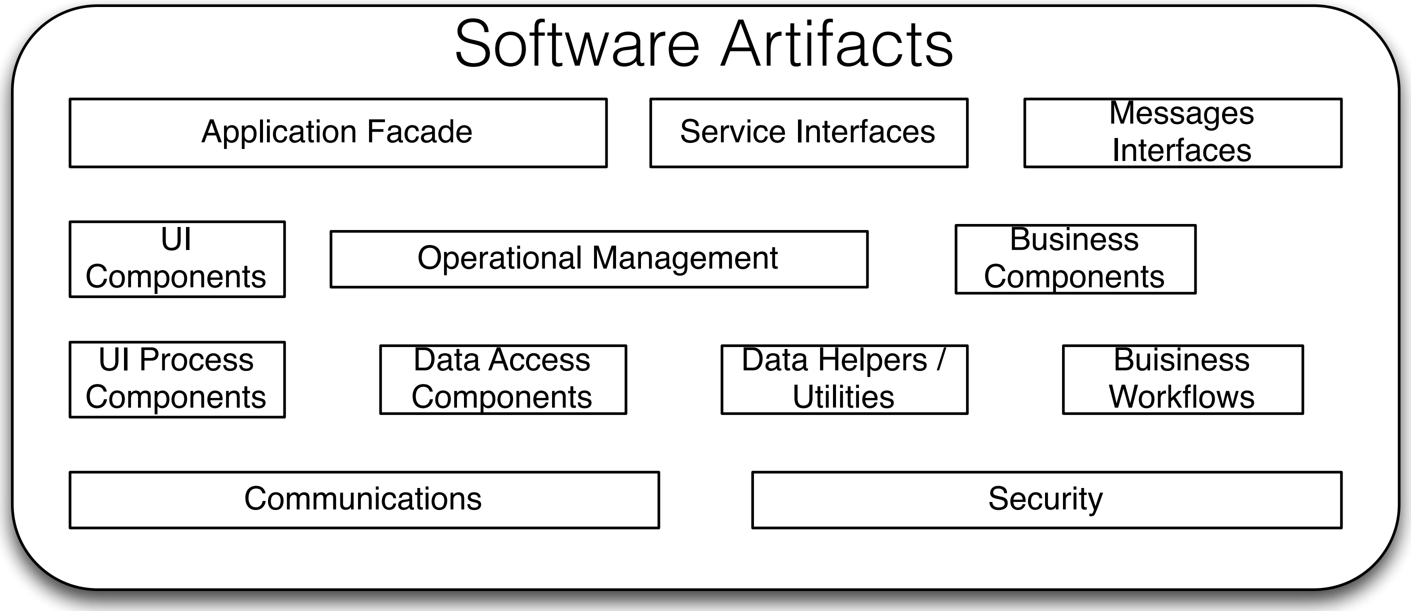




- Software Maintenance is one of the most expensive and time consuming phase of the whole life cycle
  - Anticipating the Maintenance operations reduces the cost
  - 85%-90% of the total cost are related to the effort necessary to comprehend the system and its source code [Erlikh, 2000]

SOFTWARE ARCHITECTURE

- Provide *models* and *views* representing the relationships among different **software artifacts**
  - *Clustering of Software Artifacts*



- **Advantages:**
  - To aid the comprehension
  - To reduce maintenance effort

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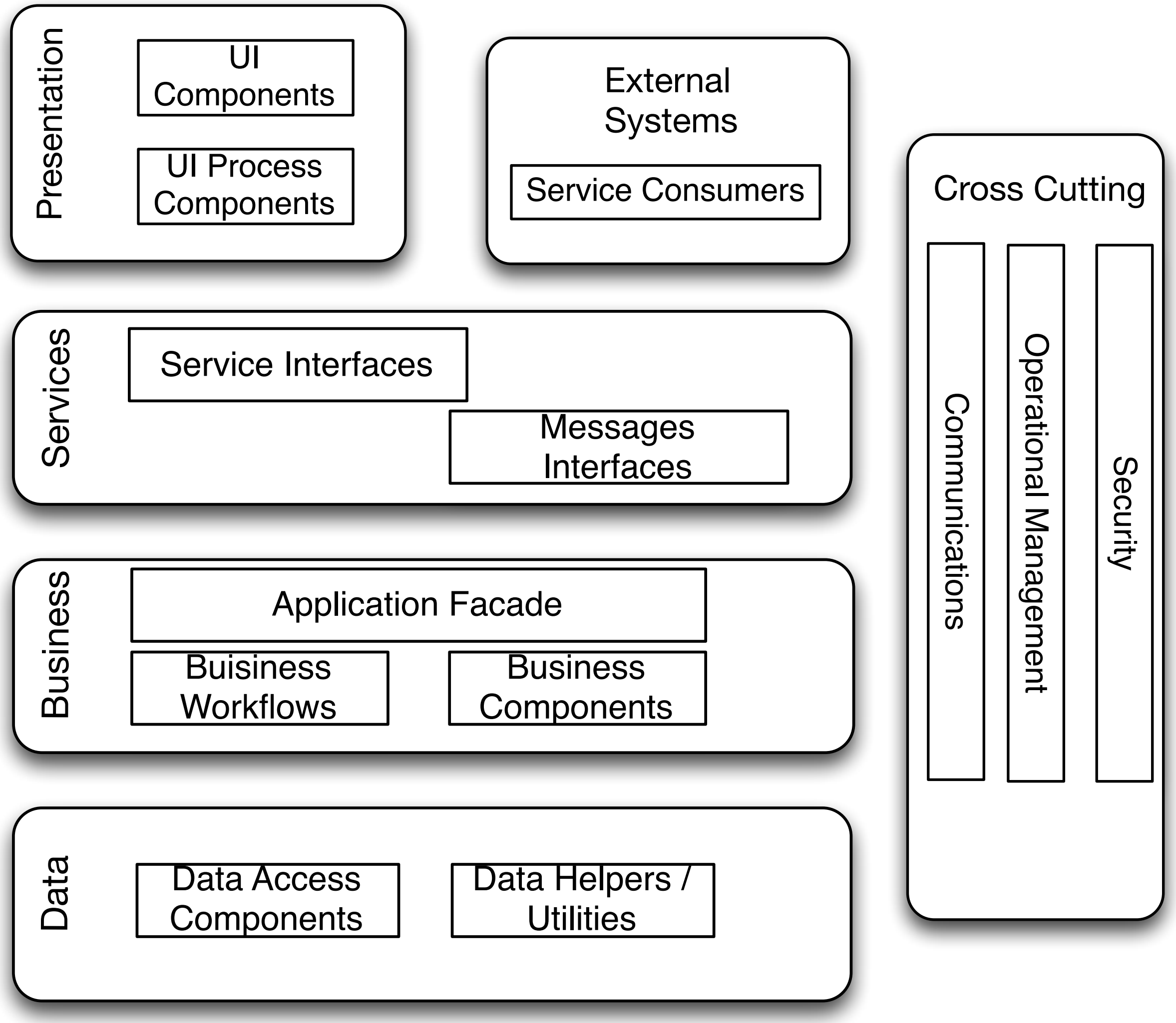
Clusters of Software Artifacts



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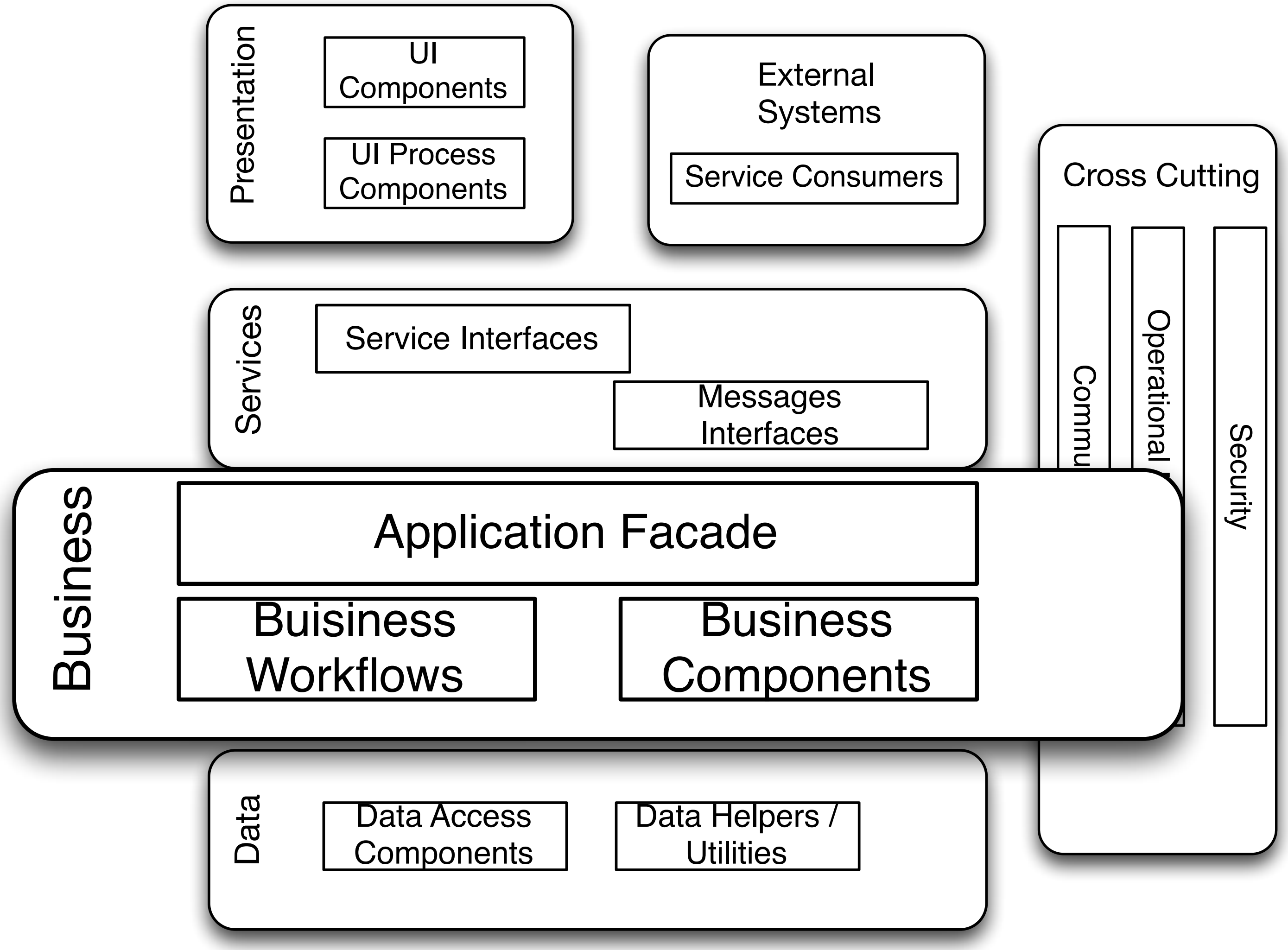
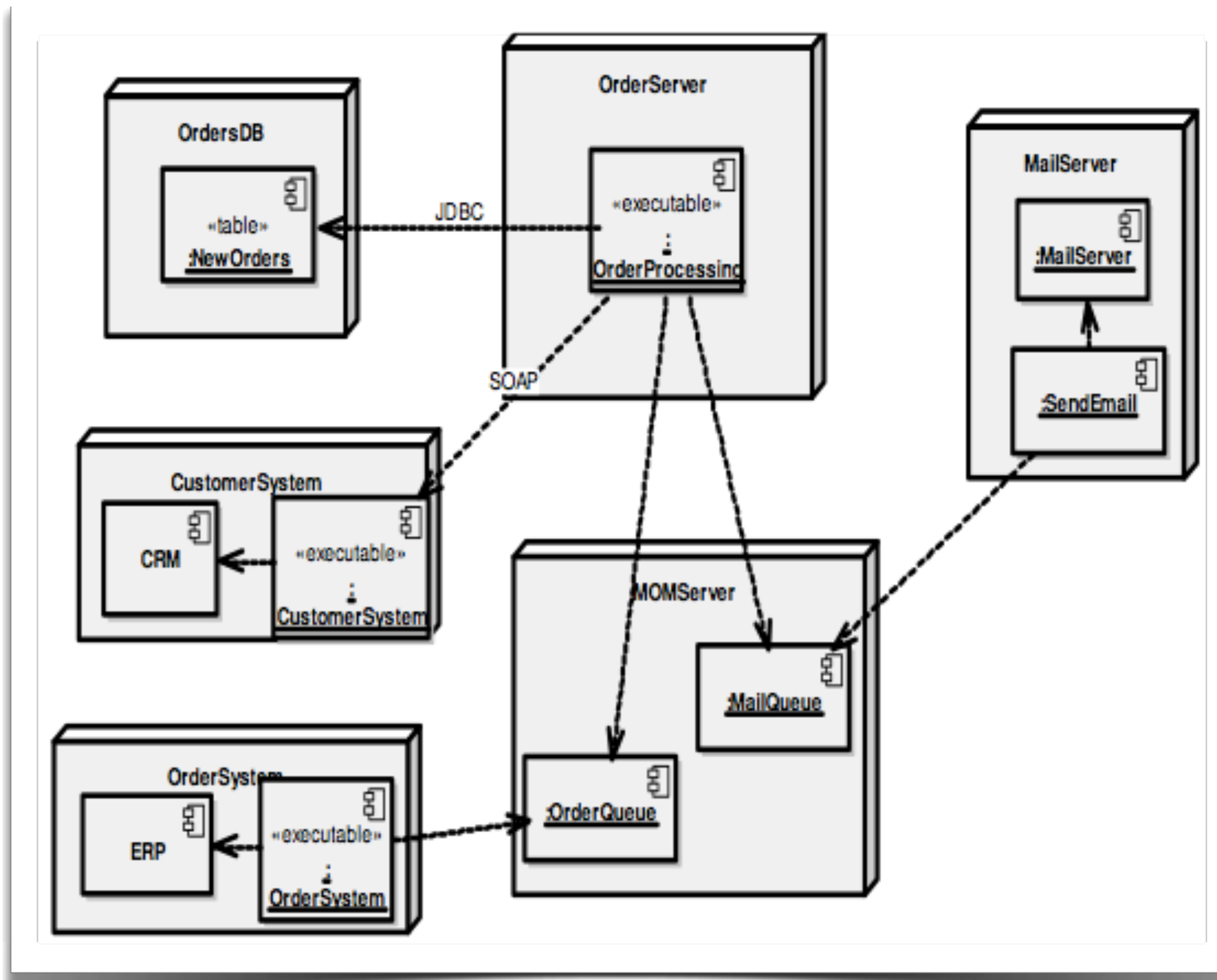


SOFTWARE ARTIFACTS

Software Artifacts may be analyzed at **different levels of abstractions**



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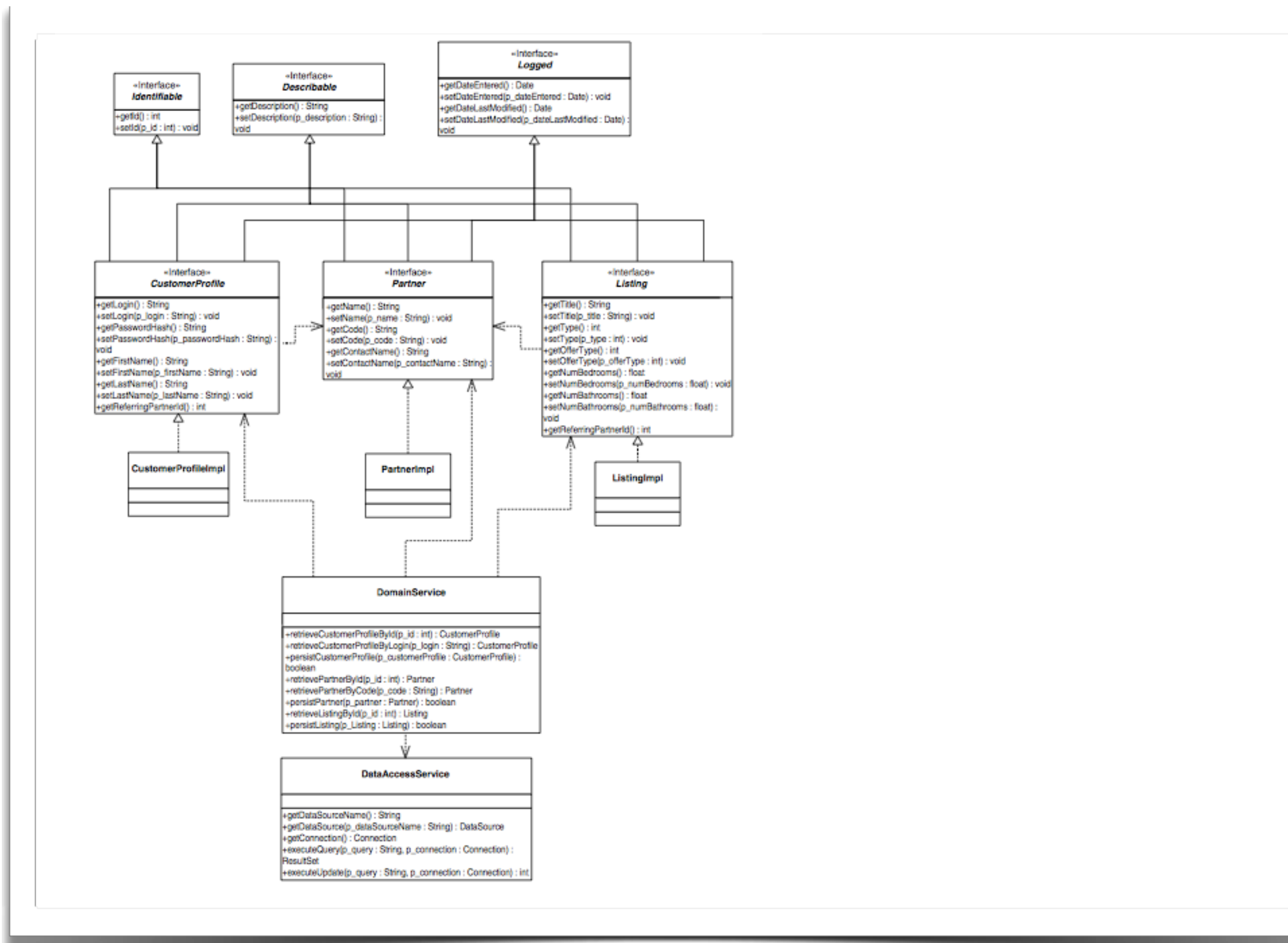

SOFTWARE ARTIFACTS

Software Artifacts may be analyzed at **different levels of abstractions**

The different levels of abstractions lead to different **analysis tasks:**

- *Identification of functional modules and their hierarchical arrangement*
  - i.e., Clustering of Software classes
- *Identification of Code Clones*
  - i.e., Clustering of Duplicated code fragments (blocks,

```
class WrappedClassLoader extends ClassLoader {
    private Bundle bundle;
    public WrappedClassLoader(Bundle bundle) {
        super();
        this.bundle = bundle;
    }
    /* (non-Javadoc)
     * @see java.lang.ClassLoader#findClass(java.lang.String)
     */
    public Class findClass(String name) throws ClassNotFoundException {
        return bundle.loadClass(name);
    }
    /* (non-Javadoc)
     * @see java.lang.ClassLoader#findResource(java.lang.String)
     */
    public URL findResource(String name) {
        return bundle.getResource(name);
    }

    /* (non-Javadoc)
     * @see java.lang.ClassLoader#findResources(java.lang.String)
     */
    protected Enumeration findResources(String name) throws IOException {
        return bundle.getResources(name);
    }
```

SOFTWARE ARTIFACTS CLUSTERING

Problem: *Definition of a proper similarity measure to apply in the clustering analysis, which is able to exploit the considered representation of software artifacts*

- Mine information directly from the source code:
  - Exploit the **syntactic/lexical information** provided in the source code text
  - Exploit the **relational information** between artifacts
    - e.g., *Program Dependencies*

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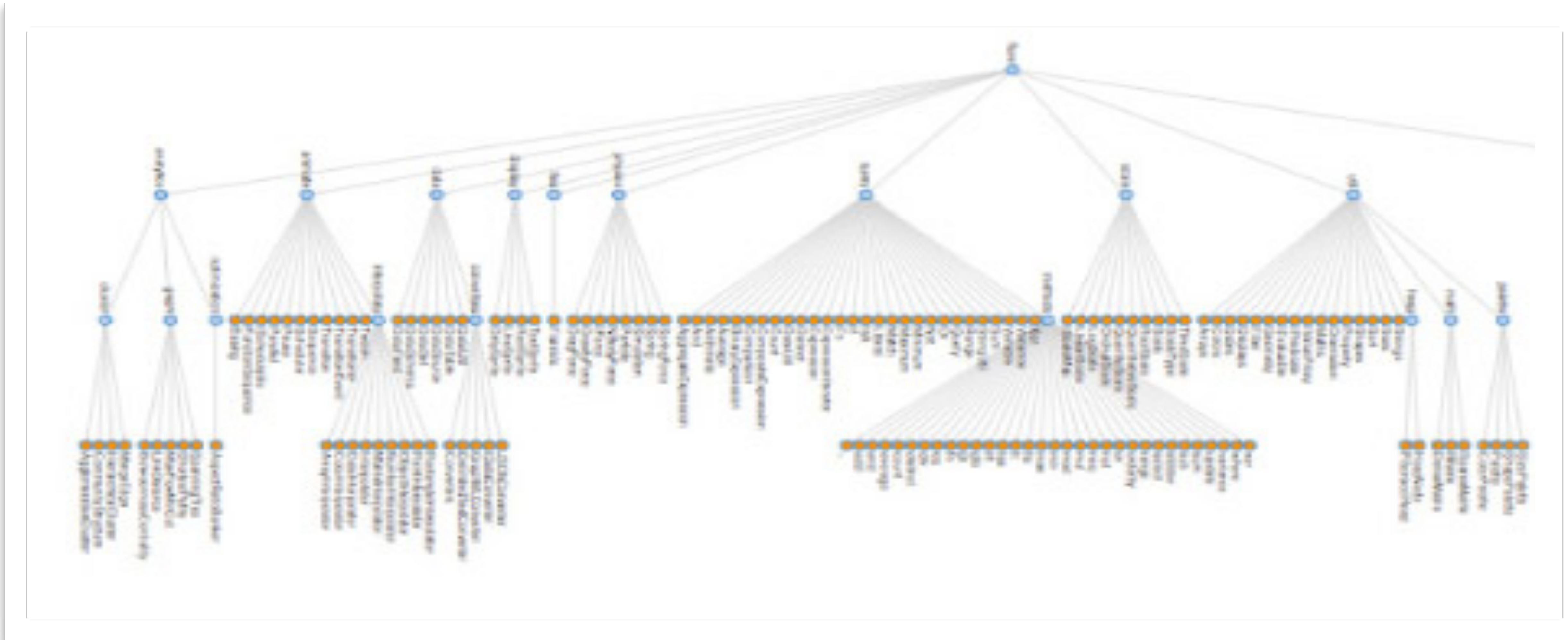
MINING LARGE REPOSITORIES



- Analysis of **large** and **complex systems**
- Solutions and algorithms must be able to **scale** efficiently (*in the large* and *in the many*)

ADVANCED MACHINE LEARNING FOR SOFTWARE MAINTENANCE

Idea: *Definition of Machine Learning techniques to mine information from the source code*

- Combine different kind of information (lexical and structural)
    - Application of **Kernel Methods** to software artifacts
- Provide flexible and computational effective solutions to analyze large data sets

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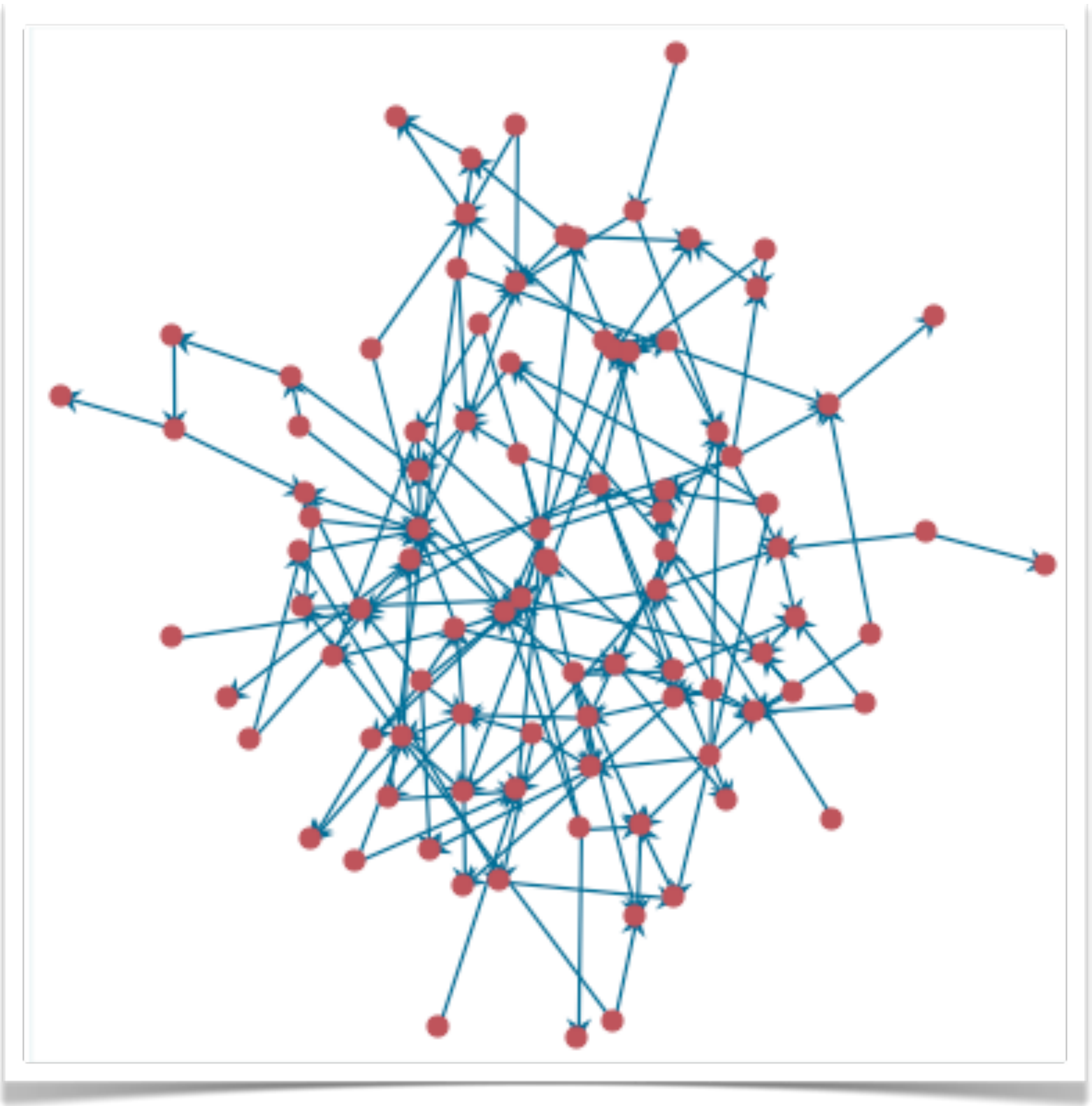
Advanced Machine Learning

- Learning with syntactic/semantic information (Natural Language Processing)
- Learning in relational domains (Structured-output learning, Logic Learning, Statistical Relational Learning)

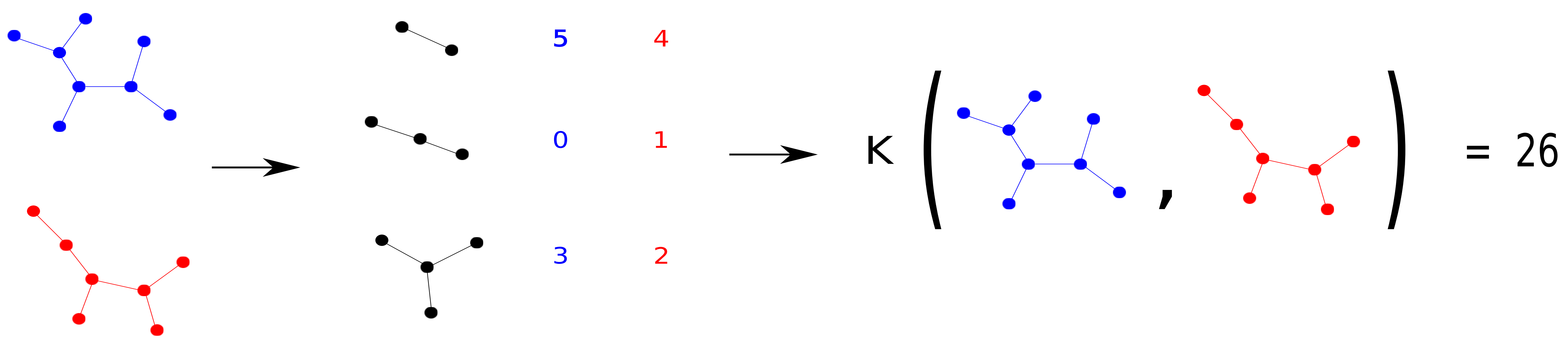
KERNEL METHODS FOR STRUCTURED DATA

- A **Kernel** is a function between (arbitrary) pairs of entities
    - It can be seen as a kind of **similarity measure**
- Based on the idea that structured objects can be described in terms of their constituent parts
- Generalize the computation of the dot product to arbitrary domains
- Can be easily tailored to specific domains
    - **Tree Kernels**
    - **Graph Kernels**
    - **....**



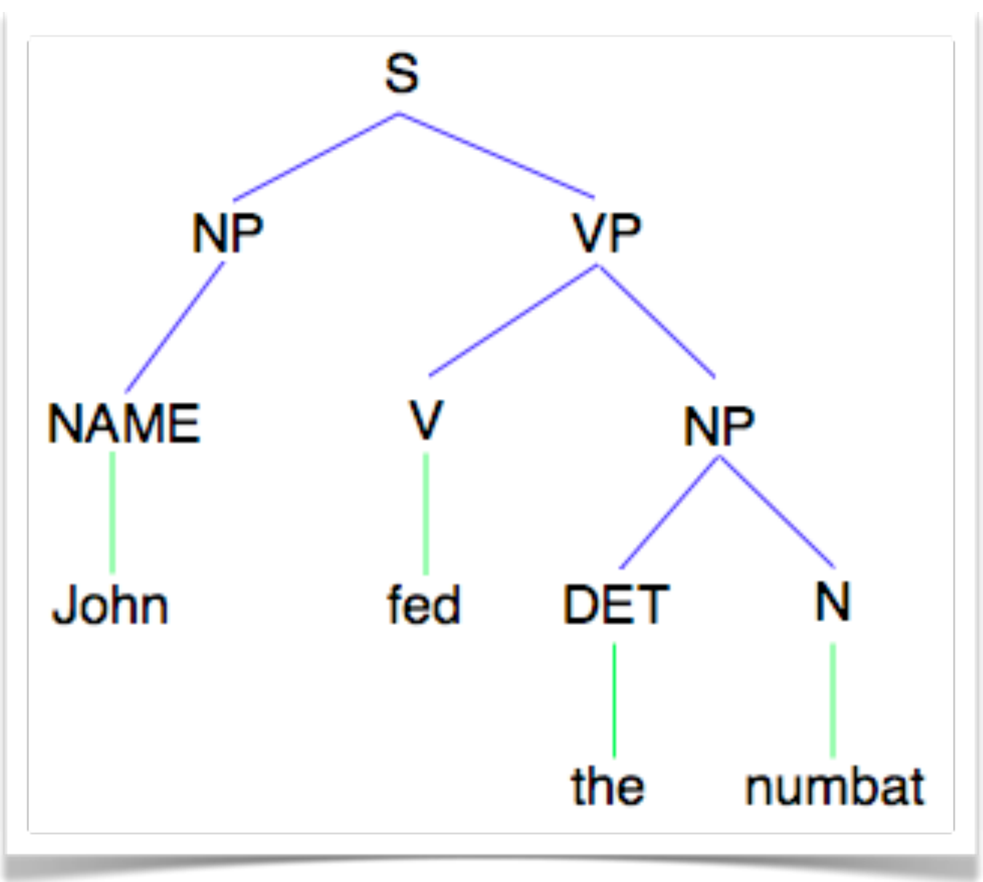
KERNELS FOR STRUCTURES

Computation of the **dot product** between (Graph) Structures



KERNELS FOR LANGUAGES

- Parse Trees represent the syntactic structure of a sentence
- Tree Kernels can be used to measure the similarity between parse trees



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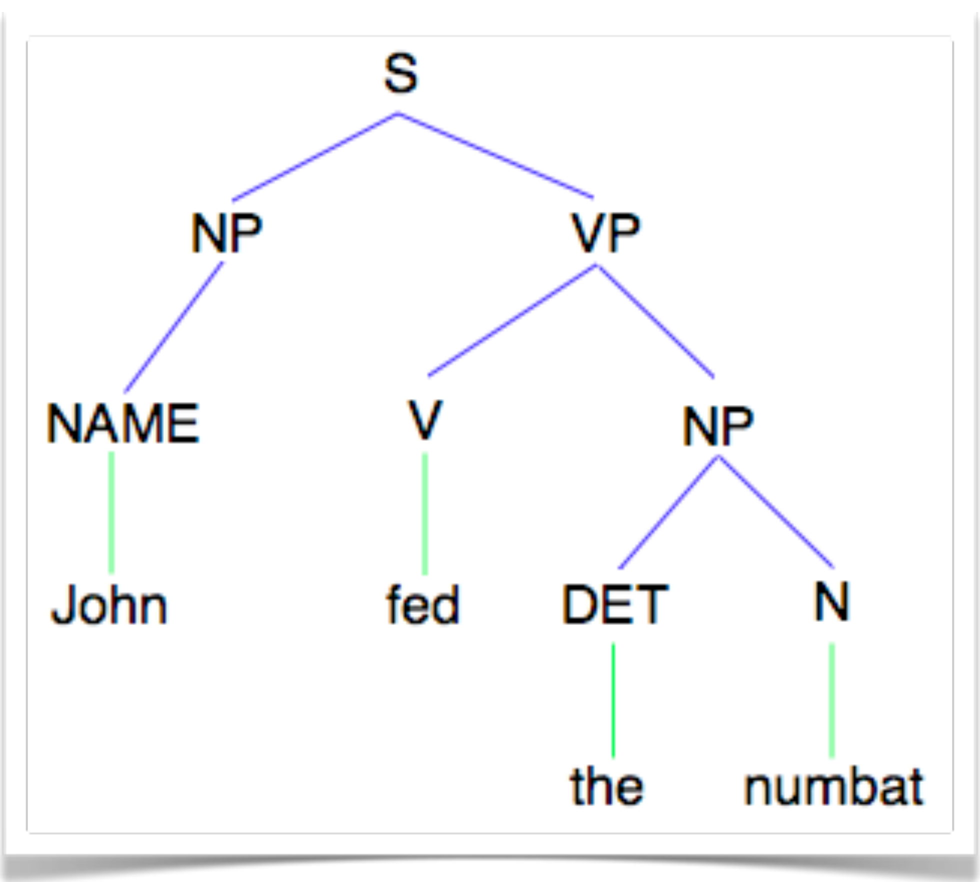
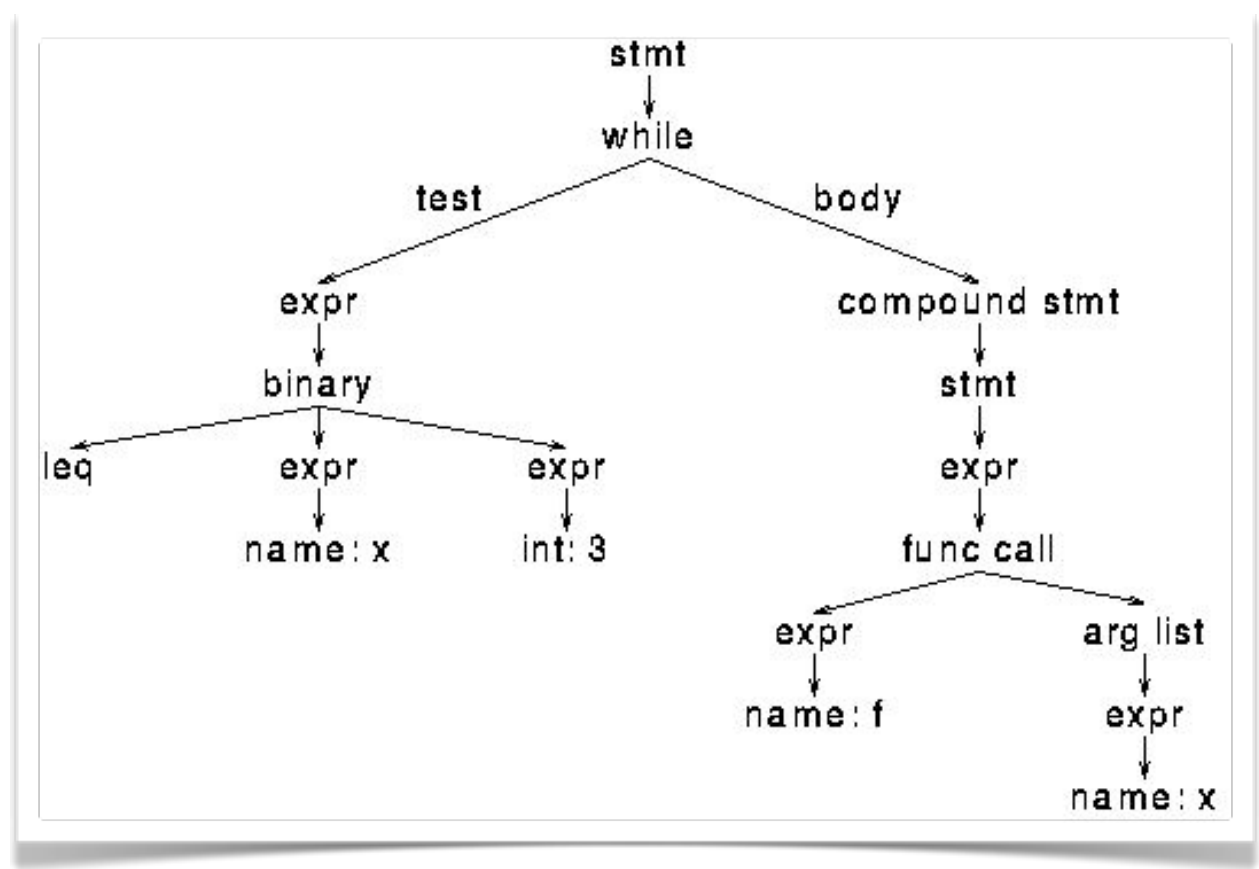


KERNELS FOR SOURCE CODE

- Abstract Syntax Trees (AST) represent the syntactic structure of a piece of code
- Research on Tree Kernels for NLP carries over to AST *(with adjustments)*



KERNELS FOR PARSE TREE

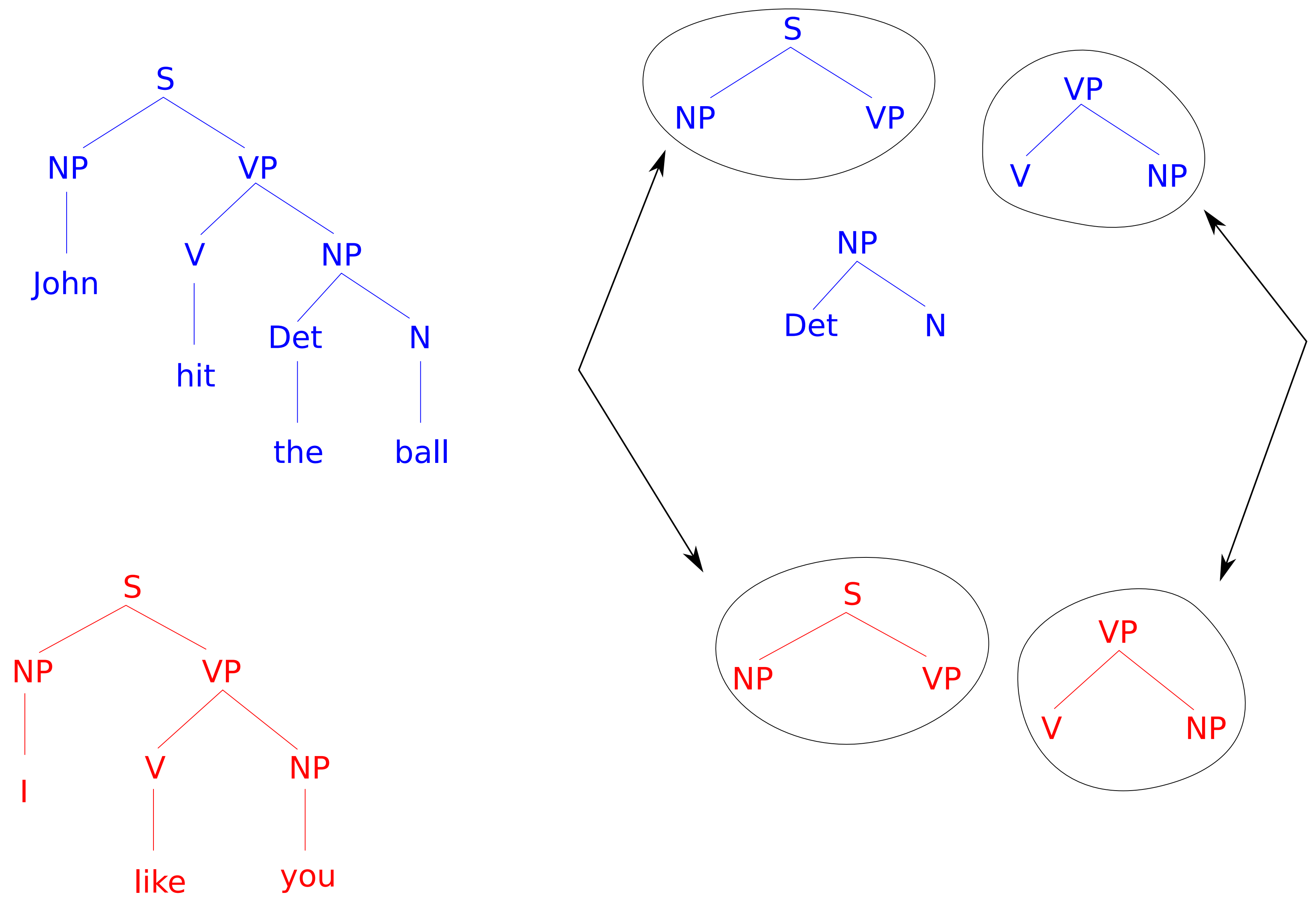
Sentence

Parse Tree

Parse Tree Kernel

John hit the ball

I like you



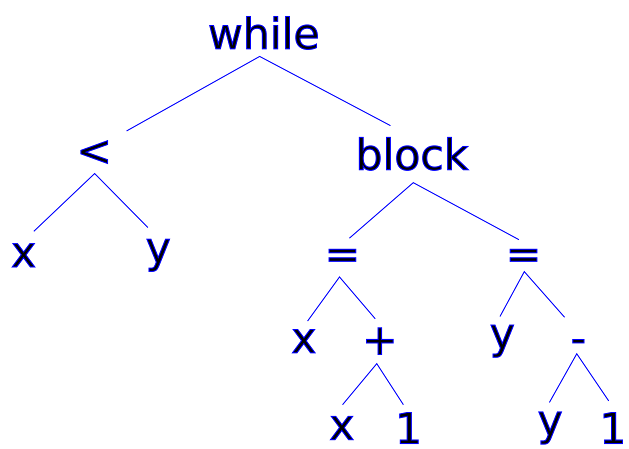
KERNELS FOR AST

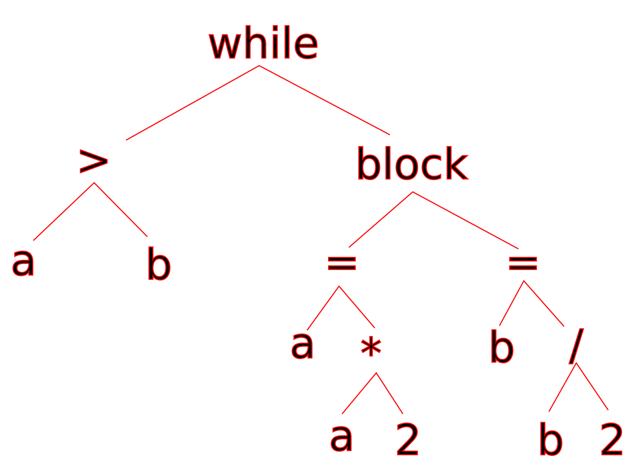
CODE

```
while (x < y) {
   x = x + 1
   y = y - 1
}
```

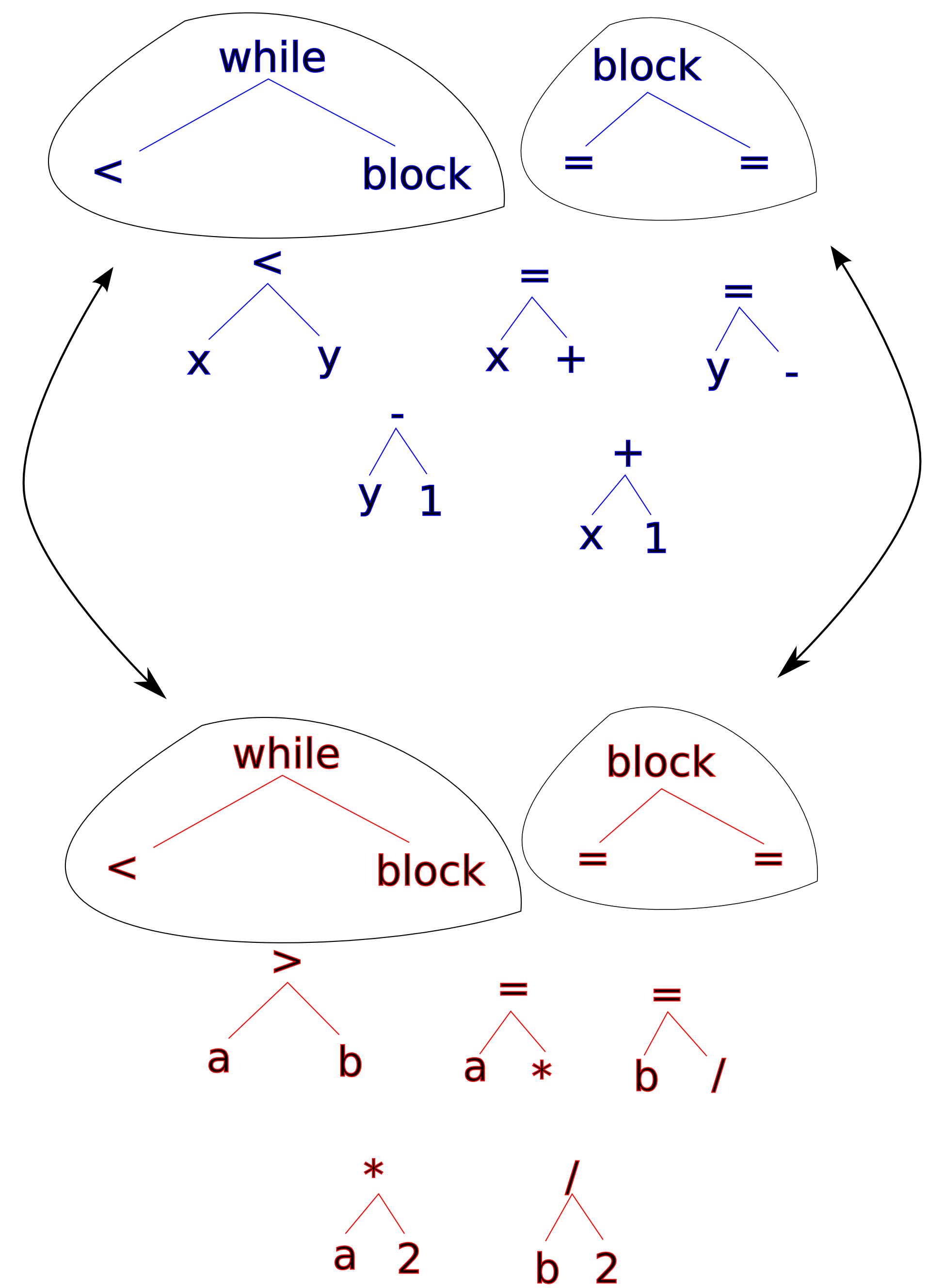
```
while (a < b) {
   a = a * 2
   b = b / 2
}
```

AST





AST KERNEL



KERNEL MACHINES

Idea: Any learning algorithm relying on similarity measure can be used

- **Supervised Learning**
  - Binary Classification
  - Multi-class Classification
  - Ranking
- **Unsupervised Learning**
  - Clustering
  - Anomaly Detection

KERNEL MACHINES FOR CONE DETECTION

- **Supervised Learning**
  - Pairwise classifier: predict if a pair of fragments is clone
- **Unsupervised Learning**
  - Clustering: cluster together all candidate clones

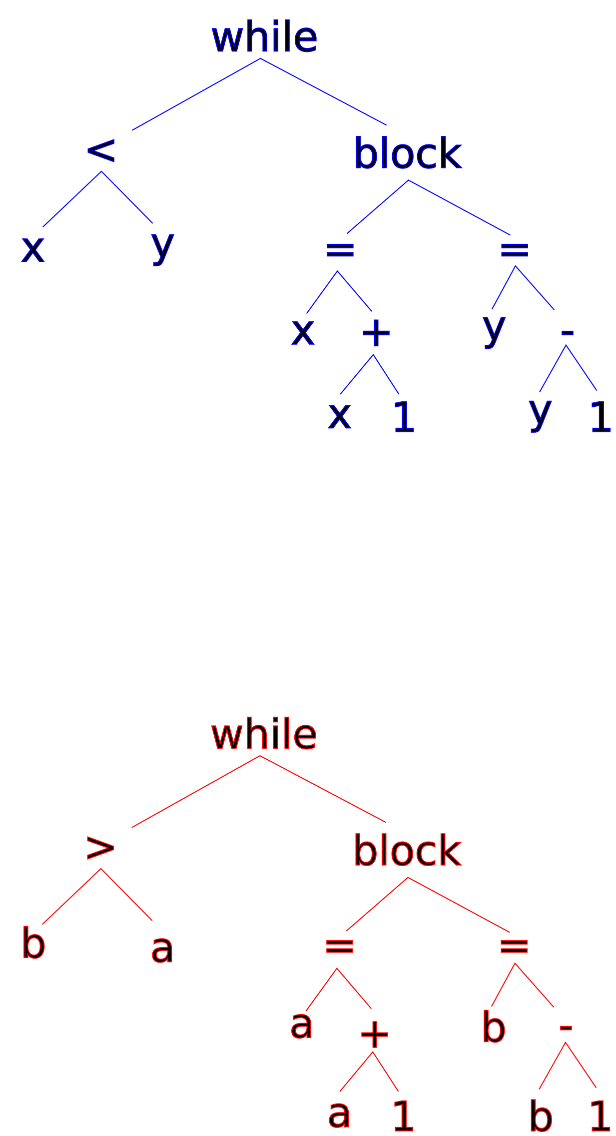
KERNEL FOR CLONES

CODE

```
while (x < y) {
  x = x + 1
  y = y - 1
}
```

```
while (b > a) {
  a = a + 1
  b = b - 1
}
```

AST



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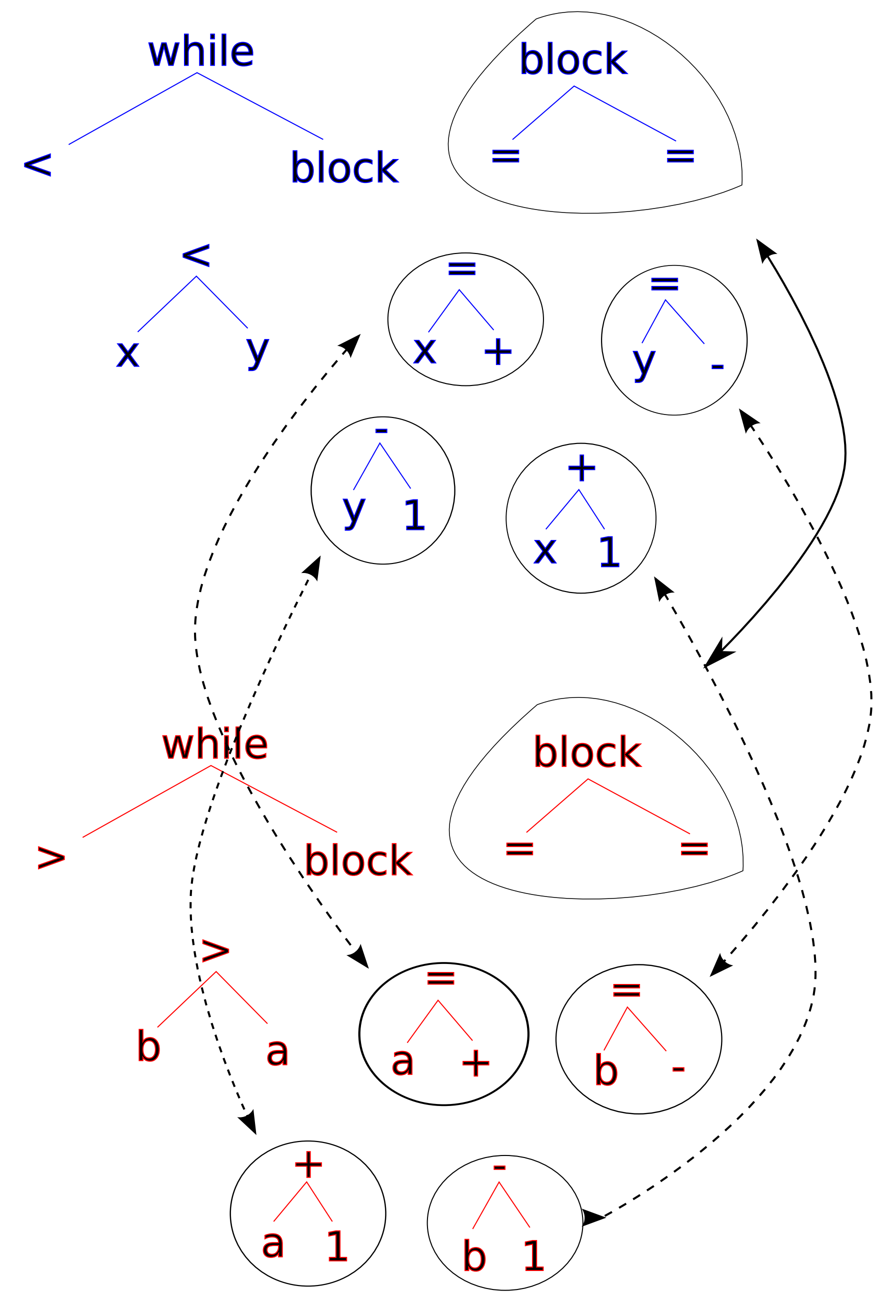


LEARNING SIMILARITIES

KERNEL LEARNING

- Construct a number of candidate kernels with different characteristics
  - *e.g., Ignore variables names or not*
- Employ kernel learning approaches which learn a weighted combination of candidate kernels
- Useless/harmful kernels will get zero weight and will be discarded in the final model

STRUCTURED-OUTPUT LEARNING

Supervised Clustering

- Exploit information on already annotated pieces of software
- Training examples are software projects/portions with annotation on existing clones (clustering)
- A learning model uses training examples to refine the similarity measure for correctly clustering novel examples

SUMMARY

- Software has a rich structure and heterogeneous information
- Advanced Machine learning approaches are promising for exploiting such information
- **Kernel Methods** are natural candidate
  - e.g., see the analogy between NLP parse trees and AST
- Many applications:
  - architecture recovery, code clone detection, vulnerability detection ....

CASE STUDY: KERNELS FOR CLONES

CODE CLONE DETECTION

```
d_setitem(arrayobject *ap, Py_ssize_t i, PyObject *v)
{
        double x;
        if (!PyArg_Parse(v, "d;array item must be float", &x))
                return -1;
        if (i >= 0)
                    ((double *)ap->ob_item)[i] = x;
        return 0;
}
```

```
i_setitem(arrayobject *ap, Py_ssize_t i, PyObject *v)
{
        int x;
        /* 'i' == signed int, maps to PyArg_Parse's 'i' formatter */
        if (!PyArg_Parse(v, "i;array item must be integer", &x))
                return -1;
        if (i >= 0)
                    ((int *)ap->ob_item)[i] = x;
        return 0;
}
```

- **Goal**: *"Identify and group all duplicated code fragments/functions"*
  - *Copy&Paste programming*
- Taxonomy of **4 different types of clones**
  - *Program Text* similarities and *Functional* similarities
- Clones affect the reliability and the maintainability of a software system

KERNELS FOR CLONES

Kernels for Structured Data:

- The source code could be represented by many different data structures

- **Abstract Syntax Tree** (AST)
- Tree structure representing the syntactic structure of the different instructions of a program (function)

- **Program Dependencies Graph** (PDG)
  - (Directed) Graph structure representing the relationship among the different statement of a program

CODE
STRUCTURES
AST

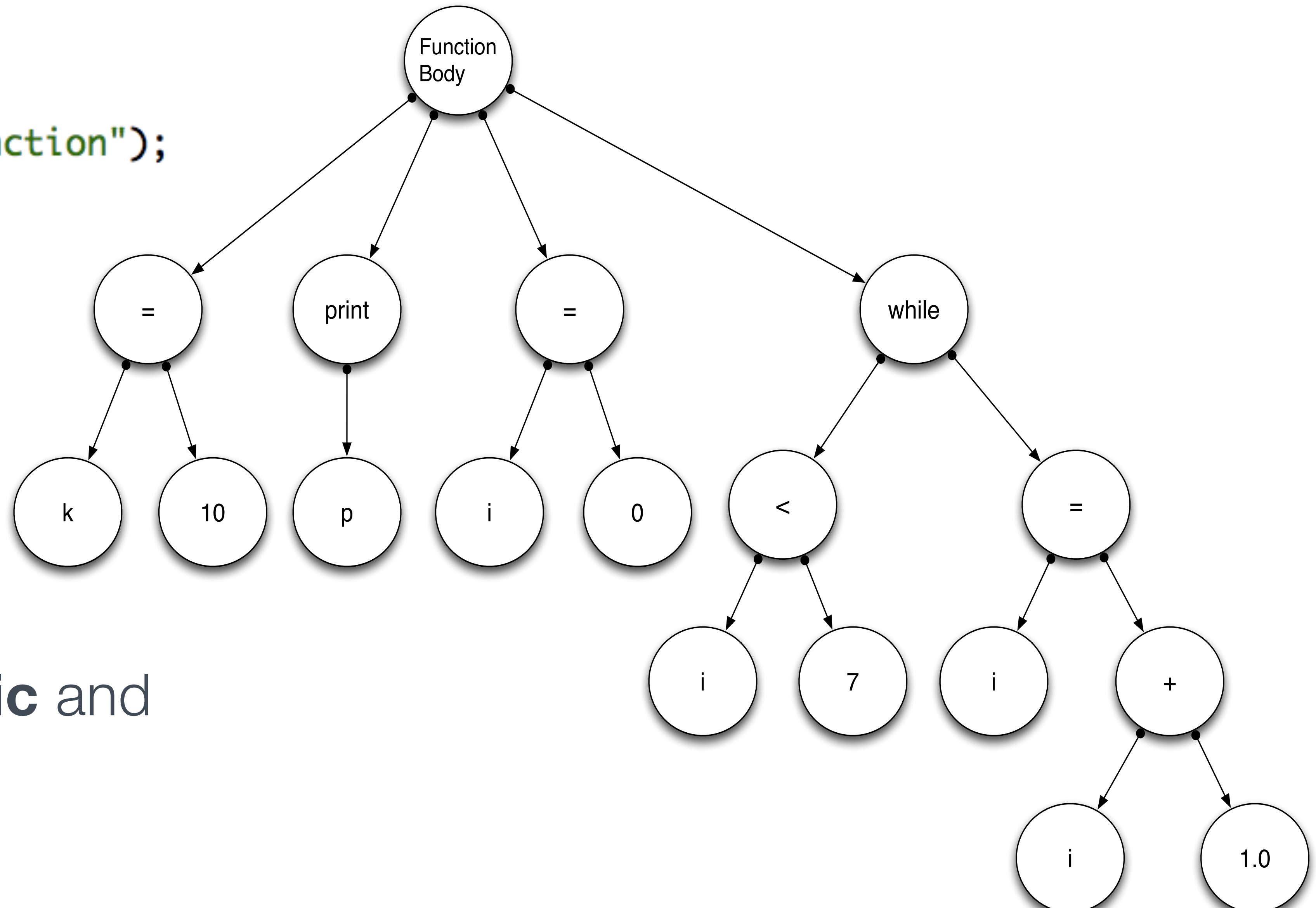
ABSTRACT SYNTAX TREE (AST)

```
int function (int parameter) {
    int k = 10;

    printf("Hello, this is the function");

    int i = 0;
    while (i < 7) {
        i++;
        // do something cool
    }

}
```



AST embeds both **Syntactic** and **Lexical** Information

- Program Instructions
- Name of Variables, Literals...

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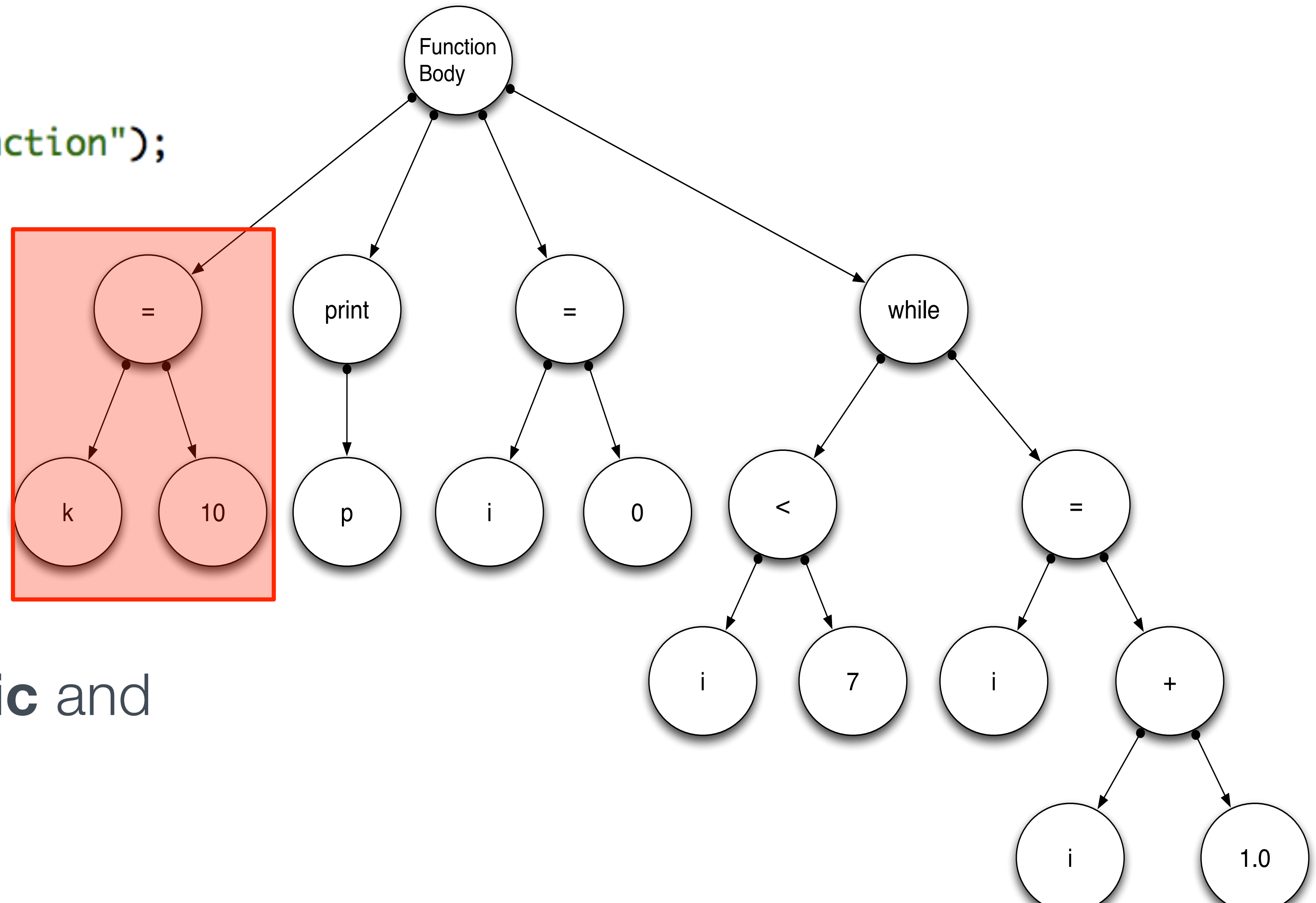

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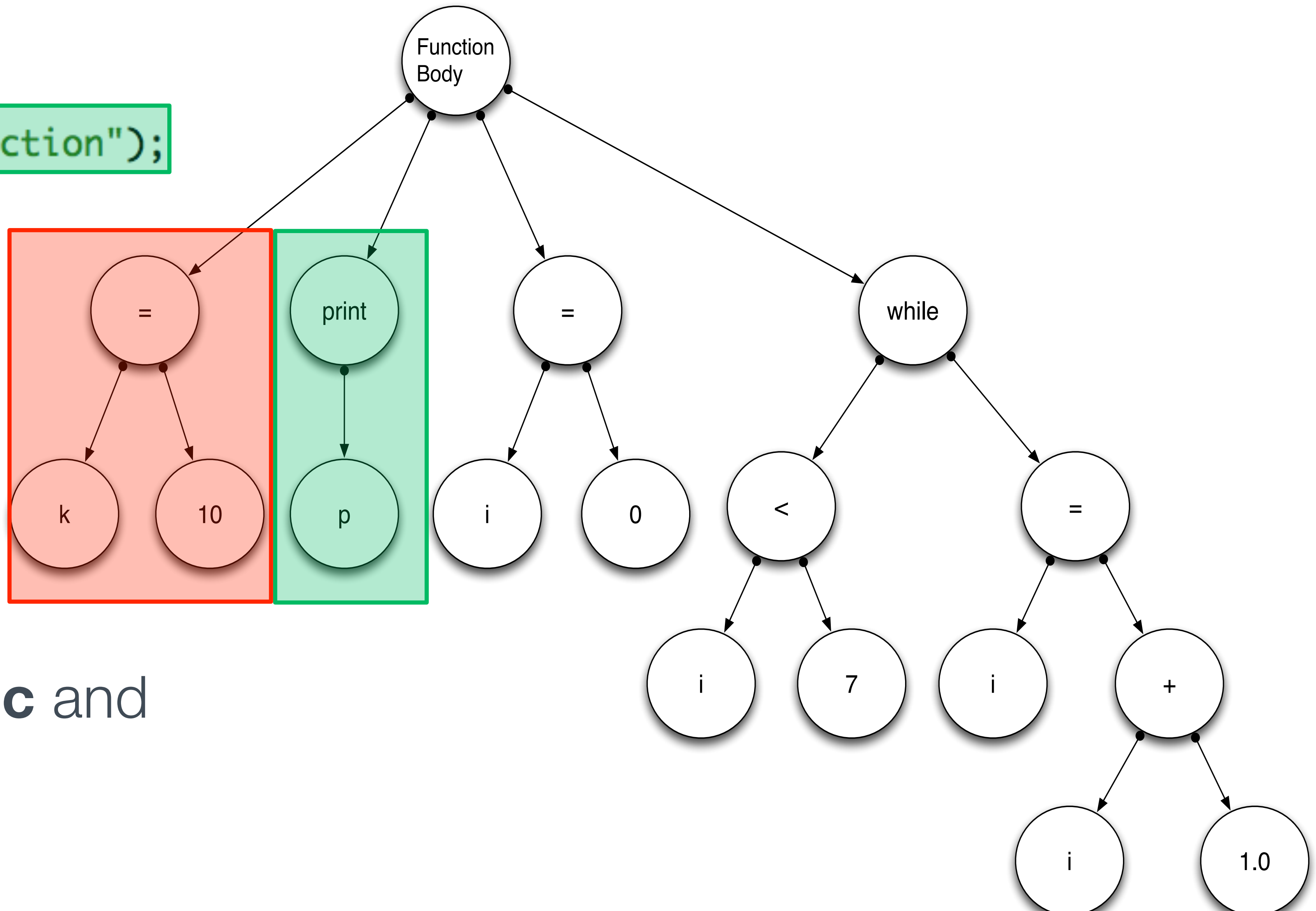

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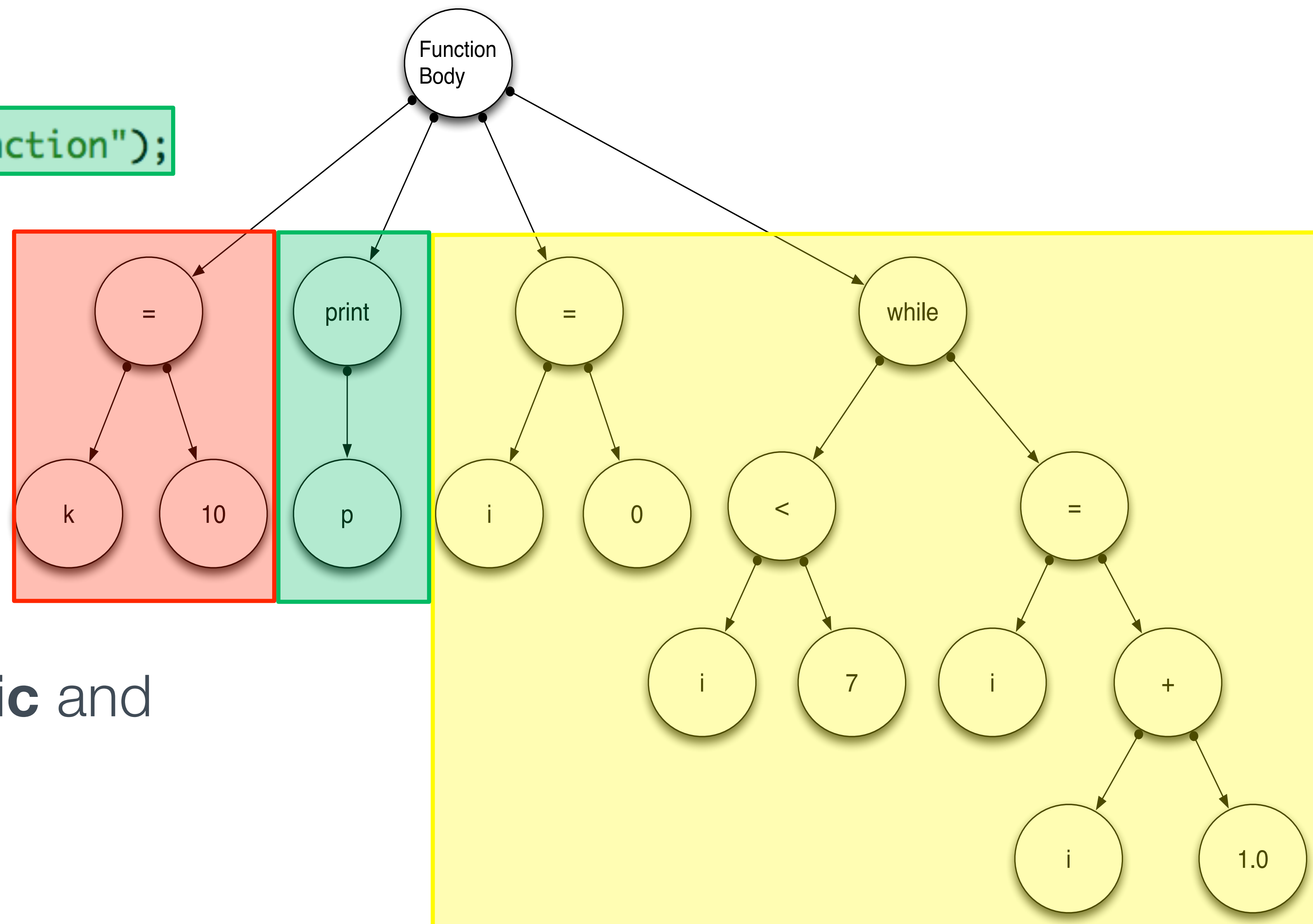

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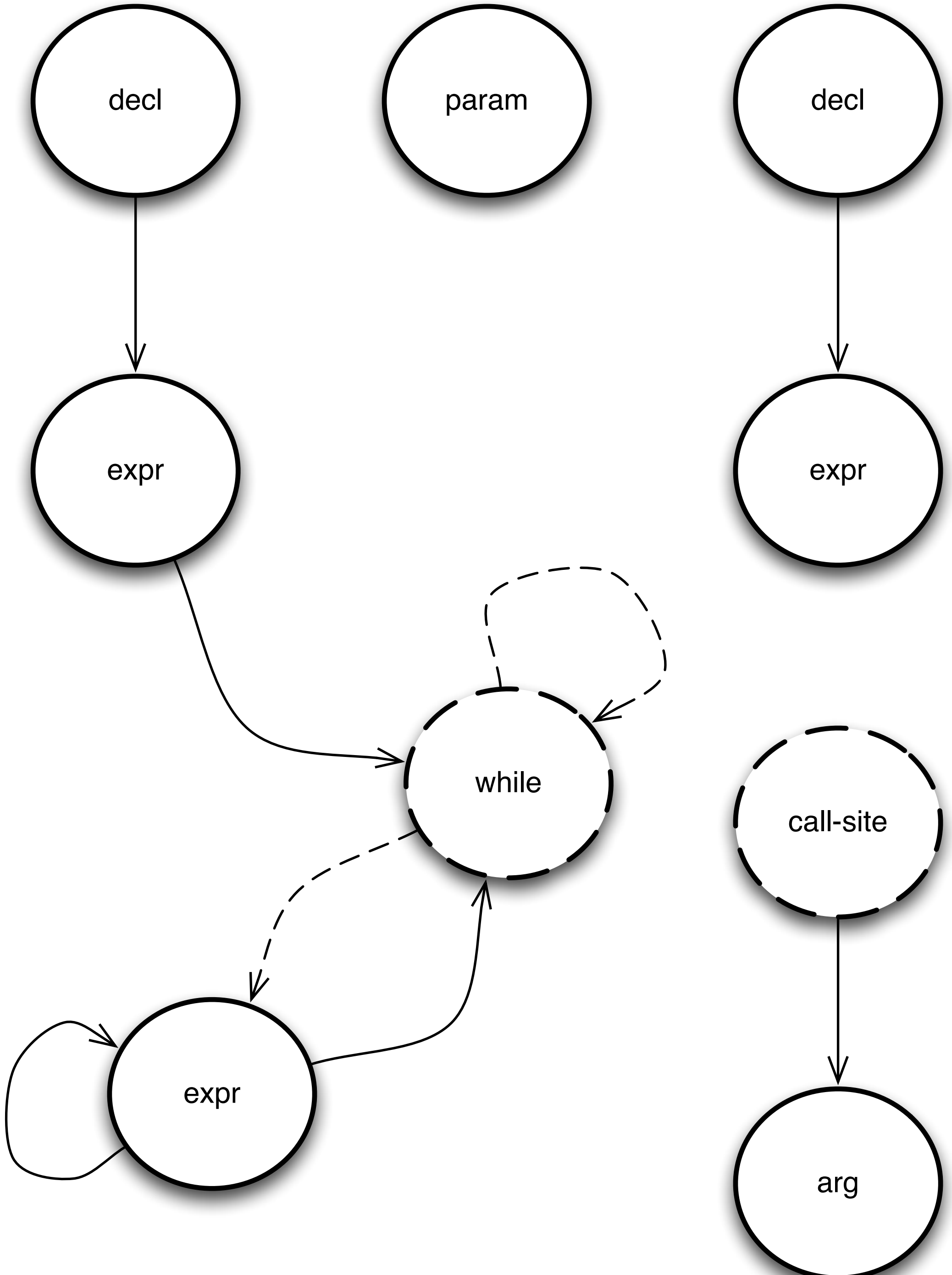

- **Nodes** correspond to instructions
- **Edges** represent relationships between couple of nodes

CODE
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PDG

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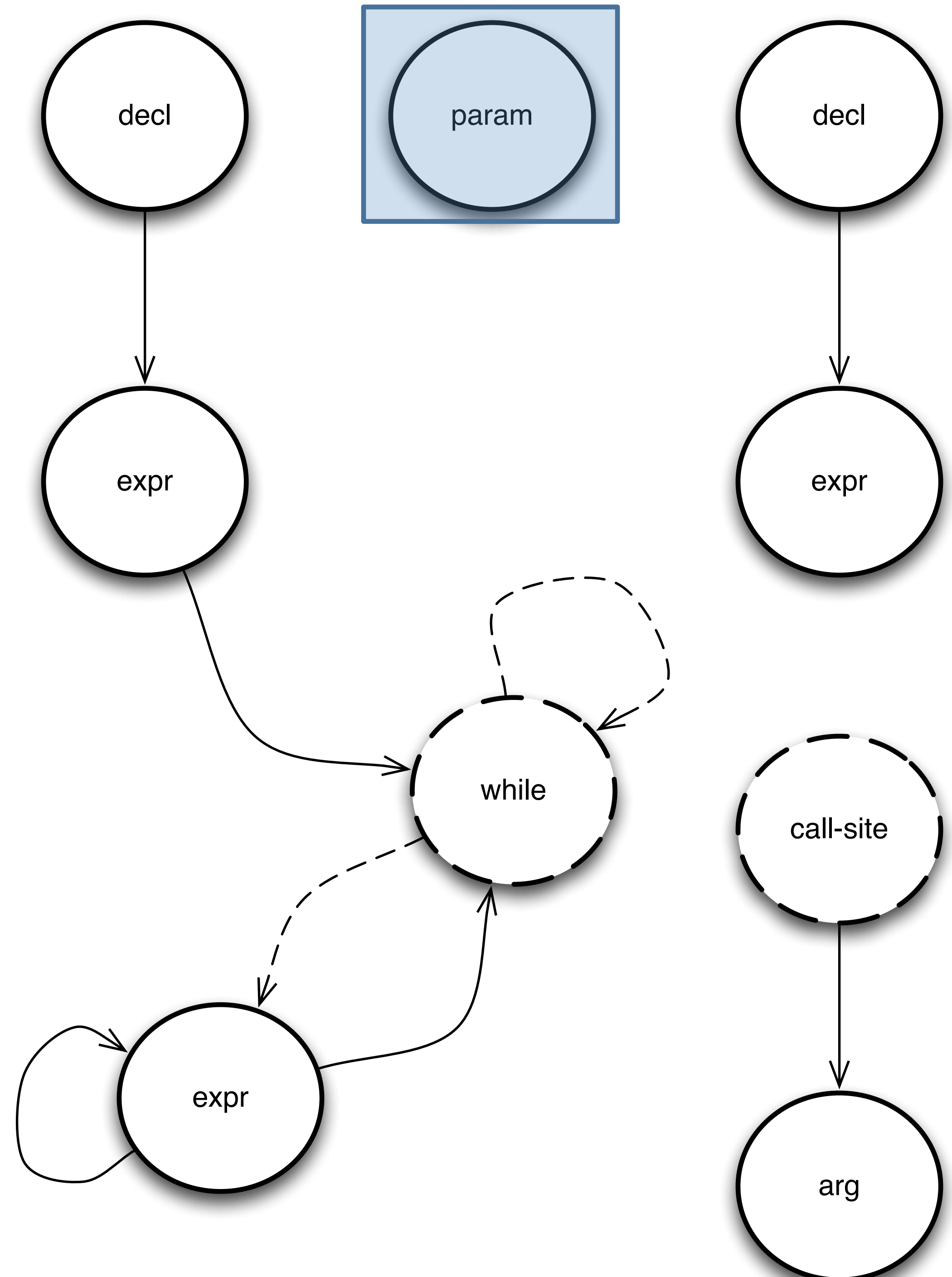

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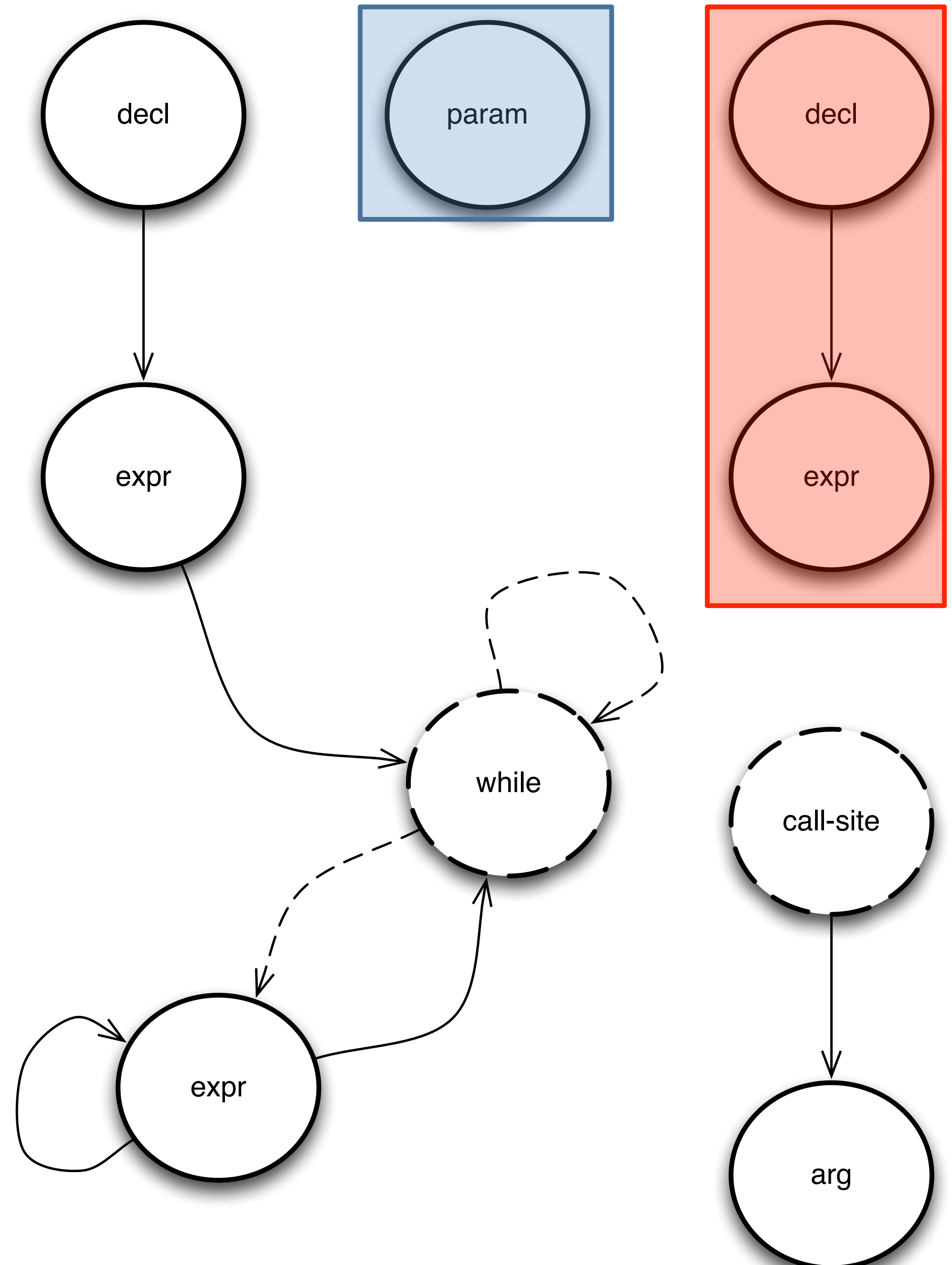

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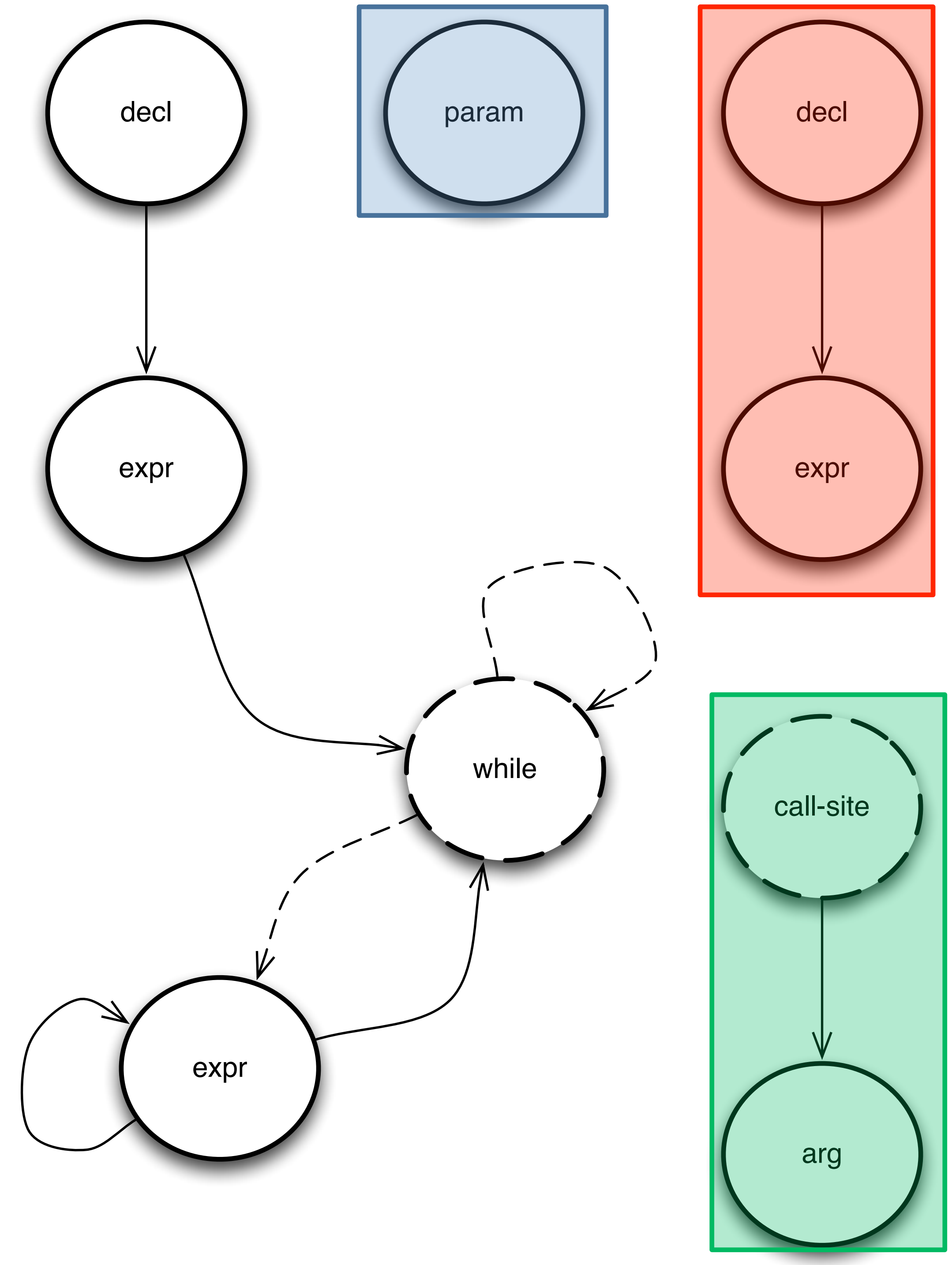

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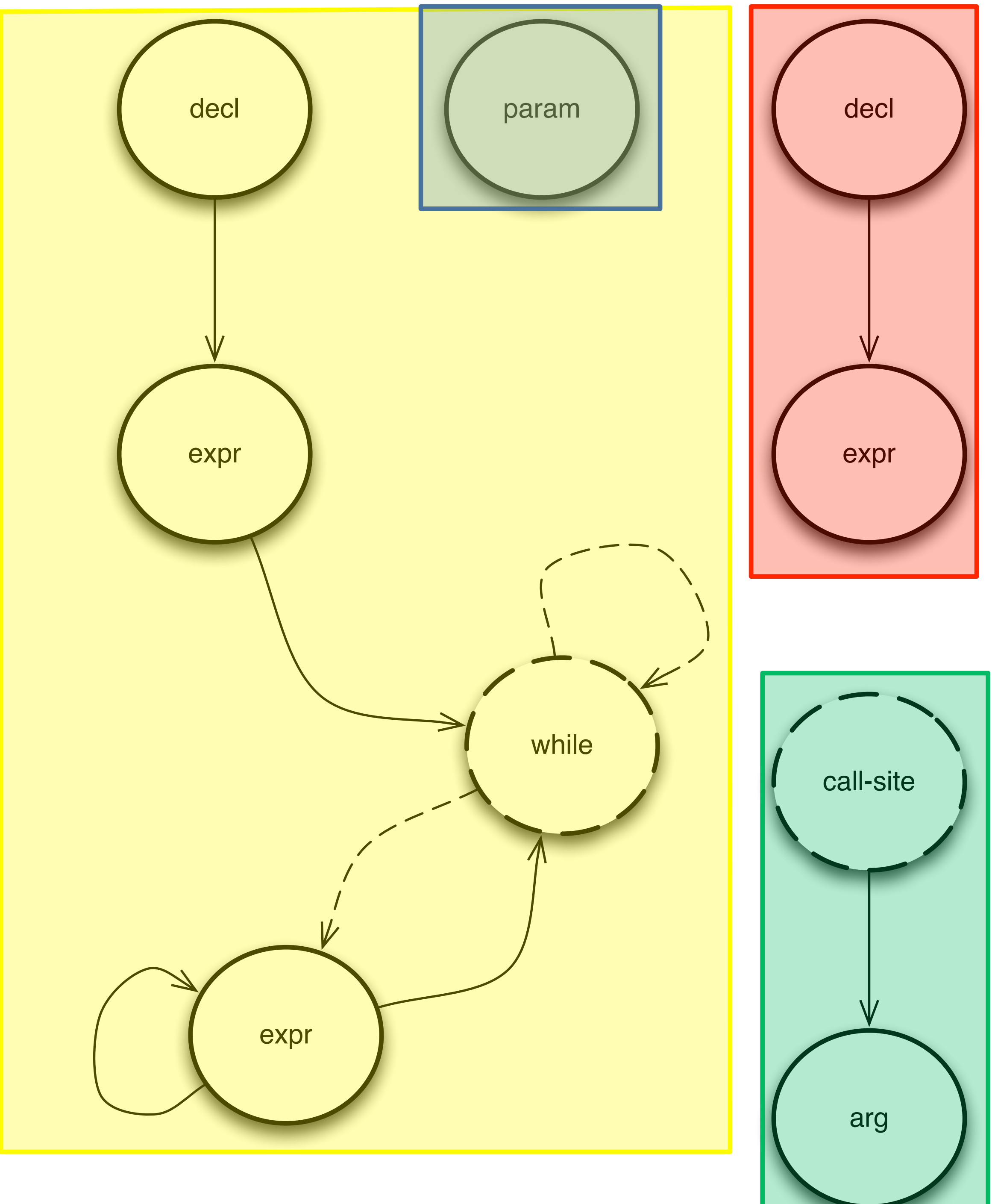

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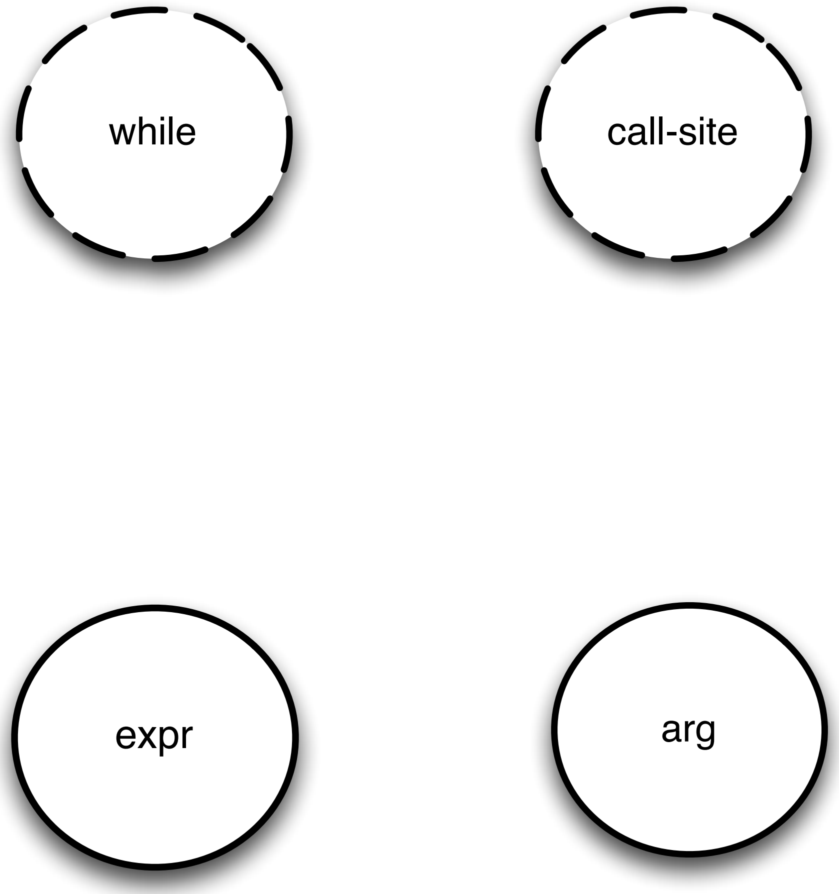
CODE
STRUCTURES
PDG

NODES AND EDGES

- **Two Types** of Nodes
  - *Control Nodes* (Dashed ones)
    - e.g., `if - for - while - function calls...`
  - *Data Nodes*
    - e.g., `expressions - parameters...`



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- **Two Types** of Edges (i.e., *dependencies*)
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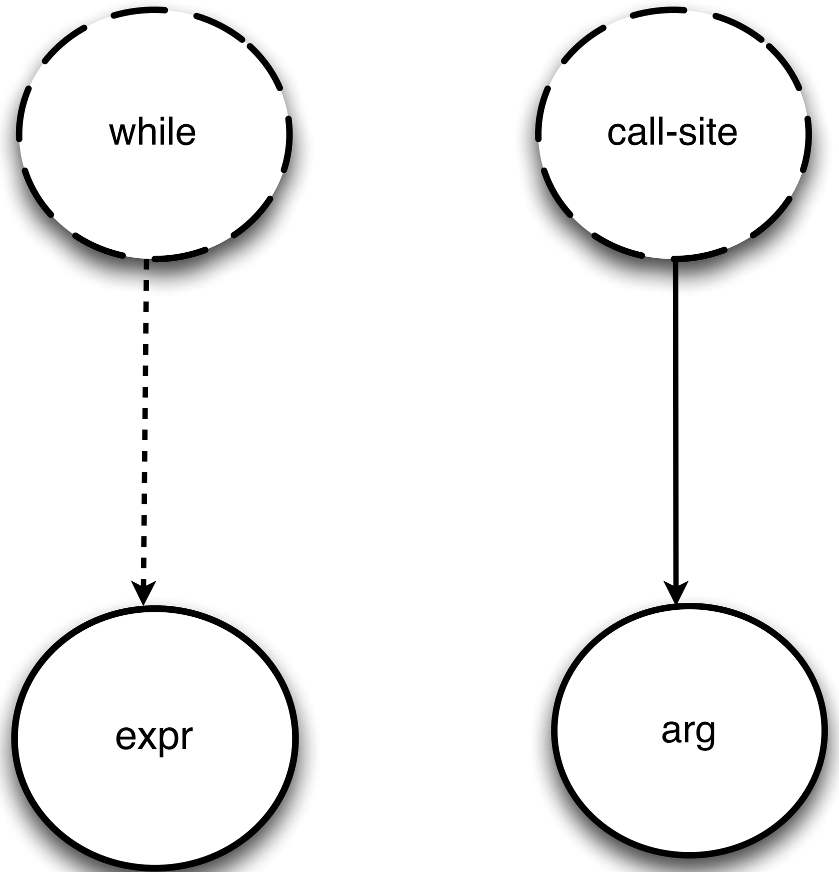
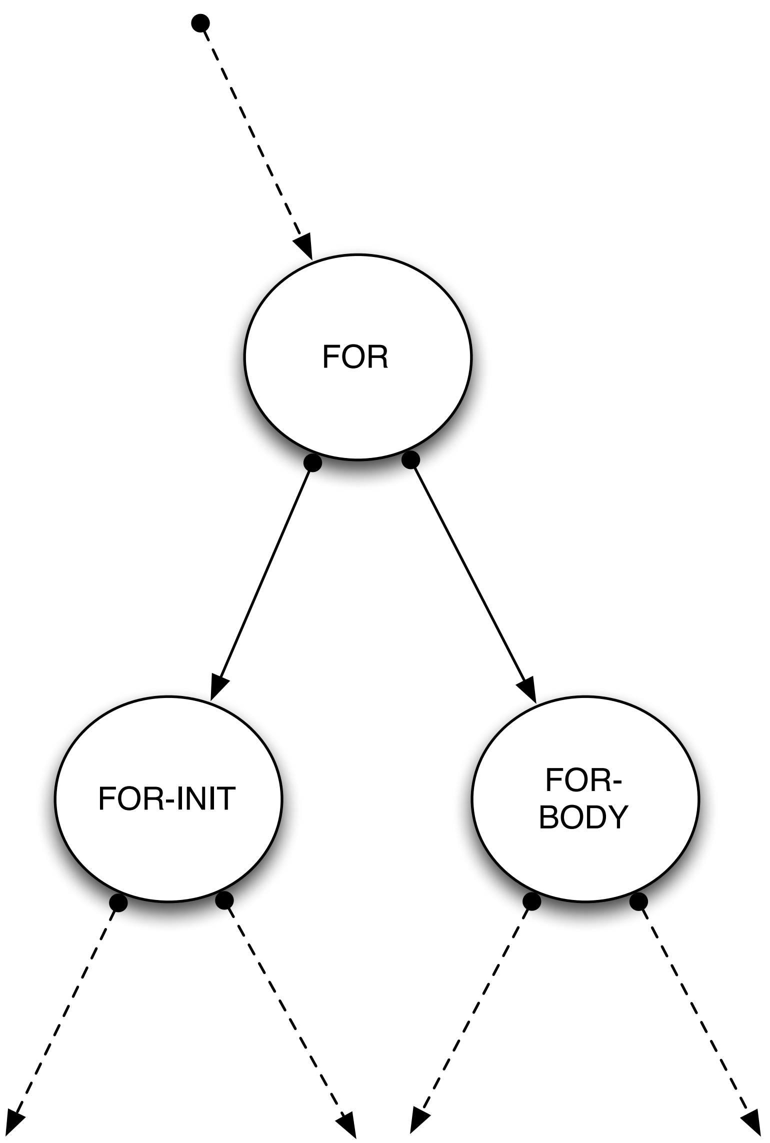


DEFINING KERNELS FOR STRUCTURED DATA

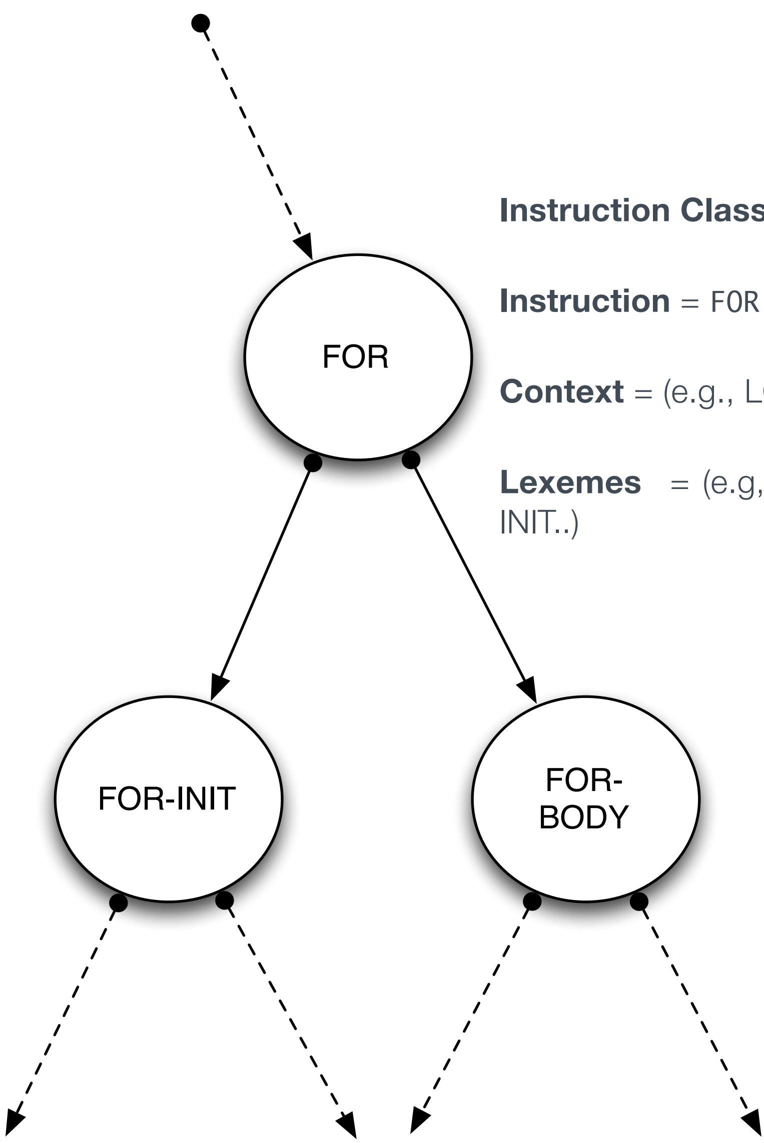
- The definition of a new Kernel for a Structured Object requires the definition of:
- Set of features to annotate each part of the object
- A Kernel function to measure the similarity on the smallest part of the object
  - *e.g., Nodes of AST and Graphs*
- A Kernel function to apply the computation on the different (sub)parts of the structured object

TREE KERNELS FOR AST



- **Features**: each node is characterized by a set of 4 features
  - **Instruction Class**
    - i.e., `LOOP, CONDITIONAL_STATEMENT, CALL`
  - **Instruction**
    - i.e., `FOR, IF, WHILE, RETURN`
  - **Context**
    - i.e., Instruction Class of the closer statement node
  - **Lexemes**
    - Lexical information gathered (recursively) from leaves

TREE KERNELS FOR AST



Instruction Class = LOOP

Instruction = FOR

Context = (e.g., LOOP)

Lexemes = (e.g, name of variables in FOR-INIT..)

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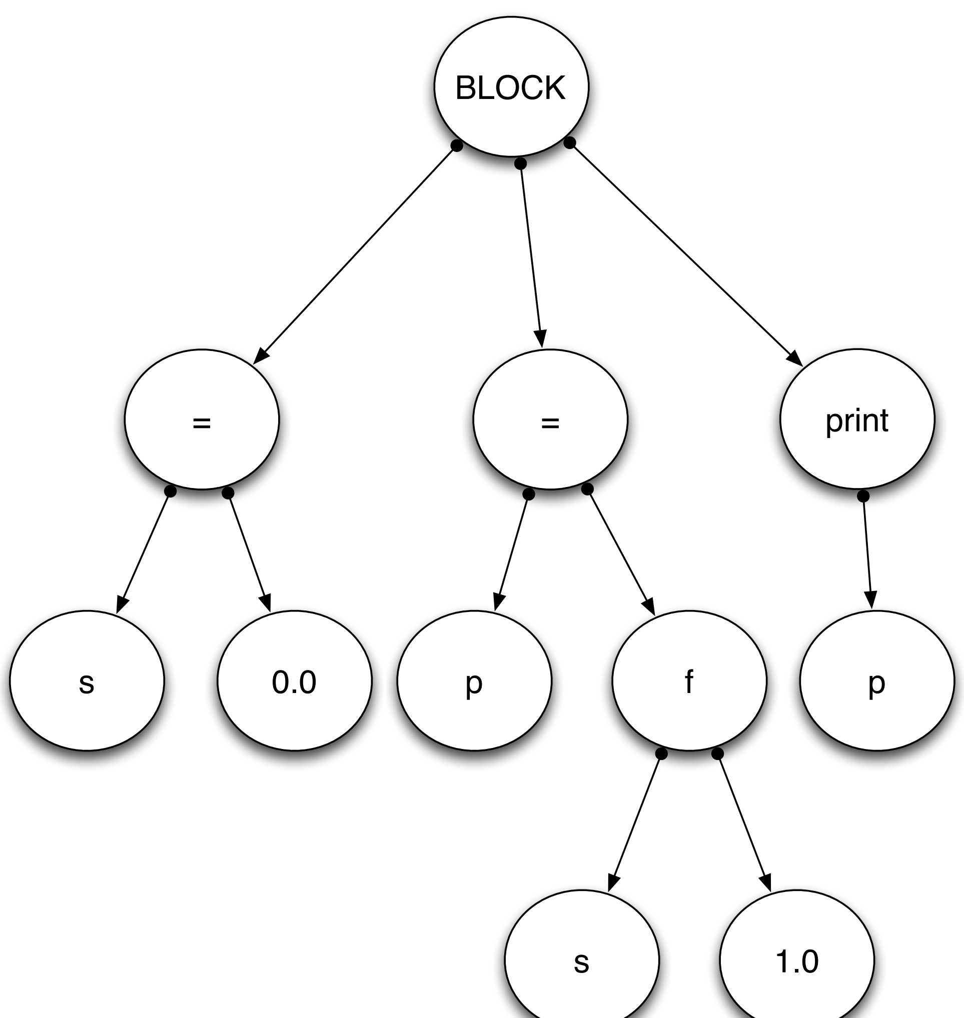
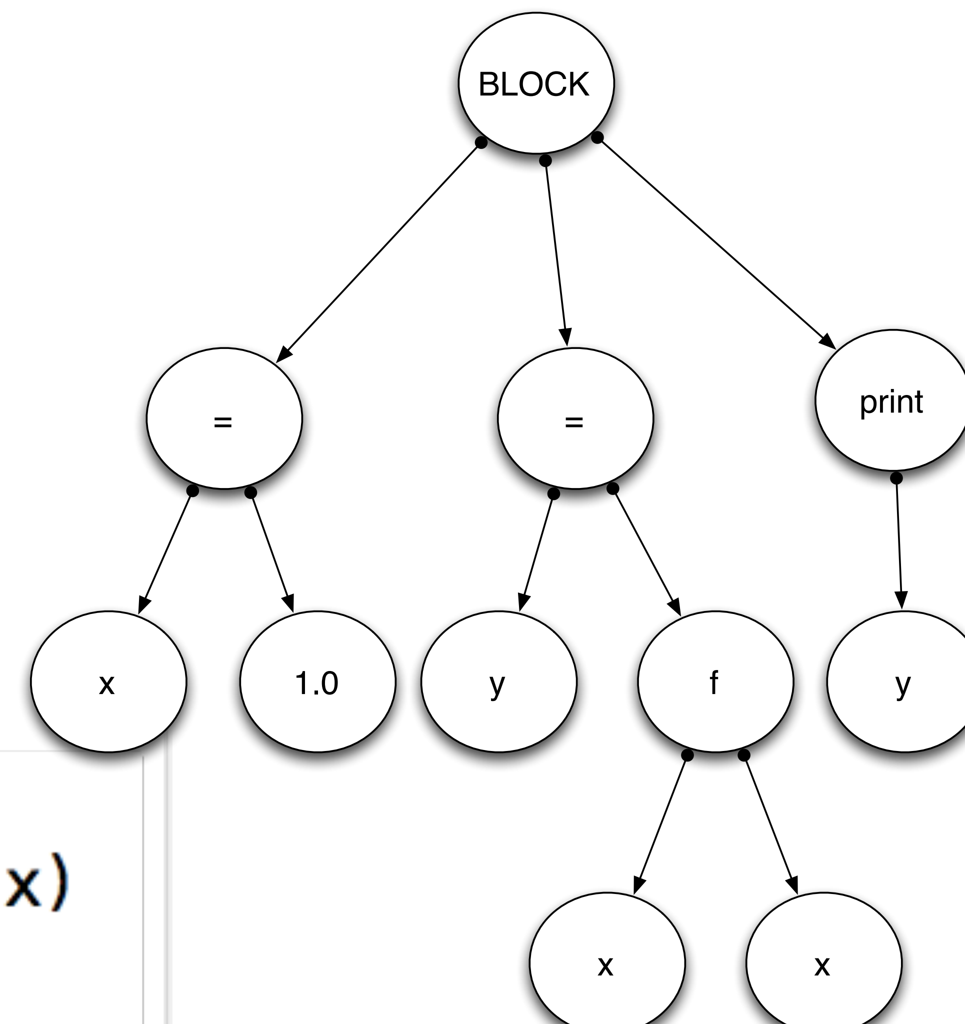
- *Comparison of blocks to each other*
- ***Blocks:*** *Atomic unit for (sub) tree considered*




```
s = 0.0
p = f(s, 1.0)
print p
```

```
x = 1.0
y = f(x, x)
print y
```



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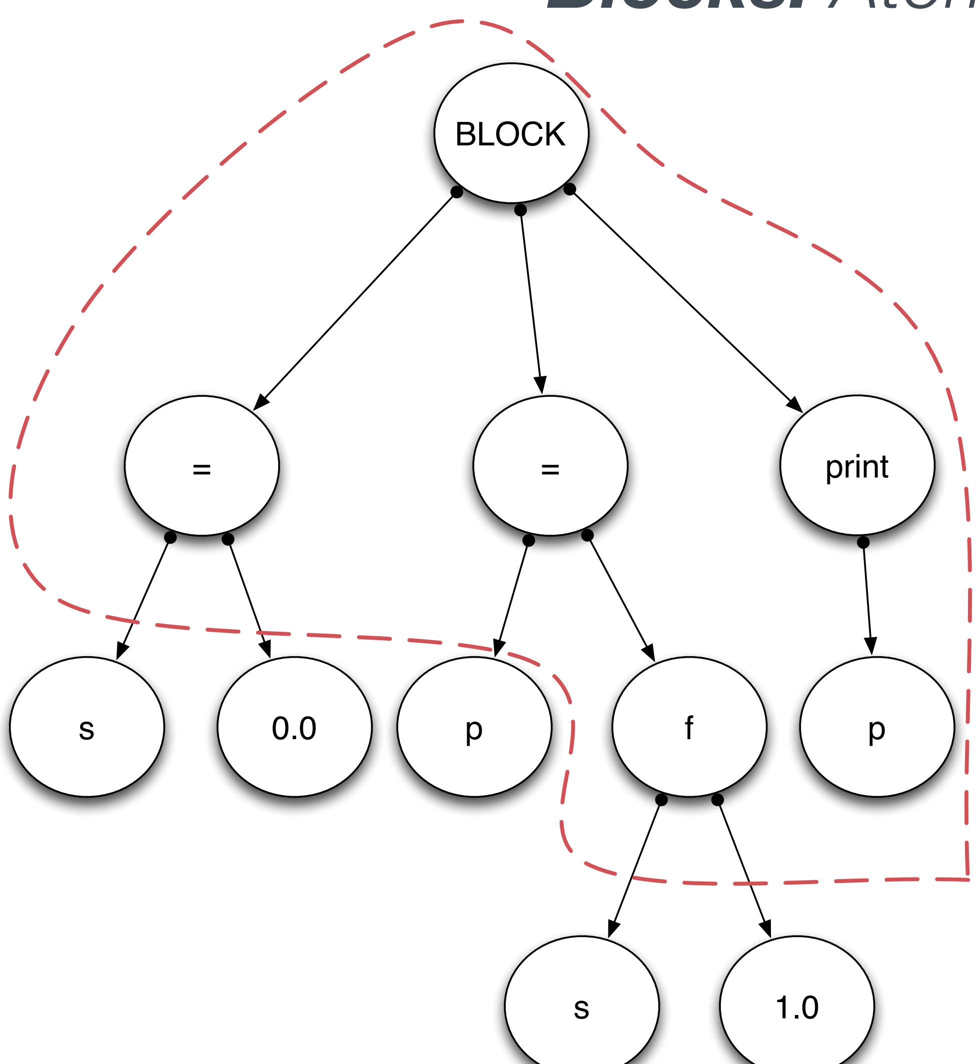


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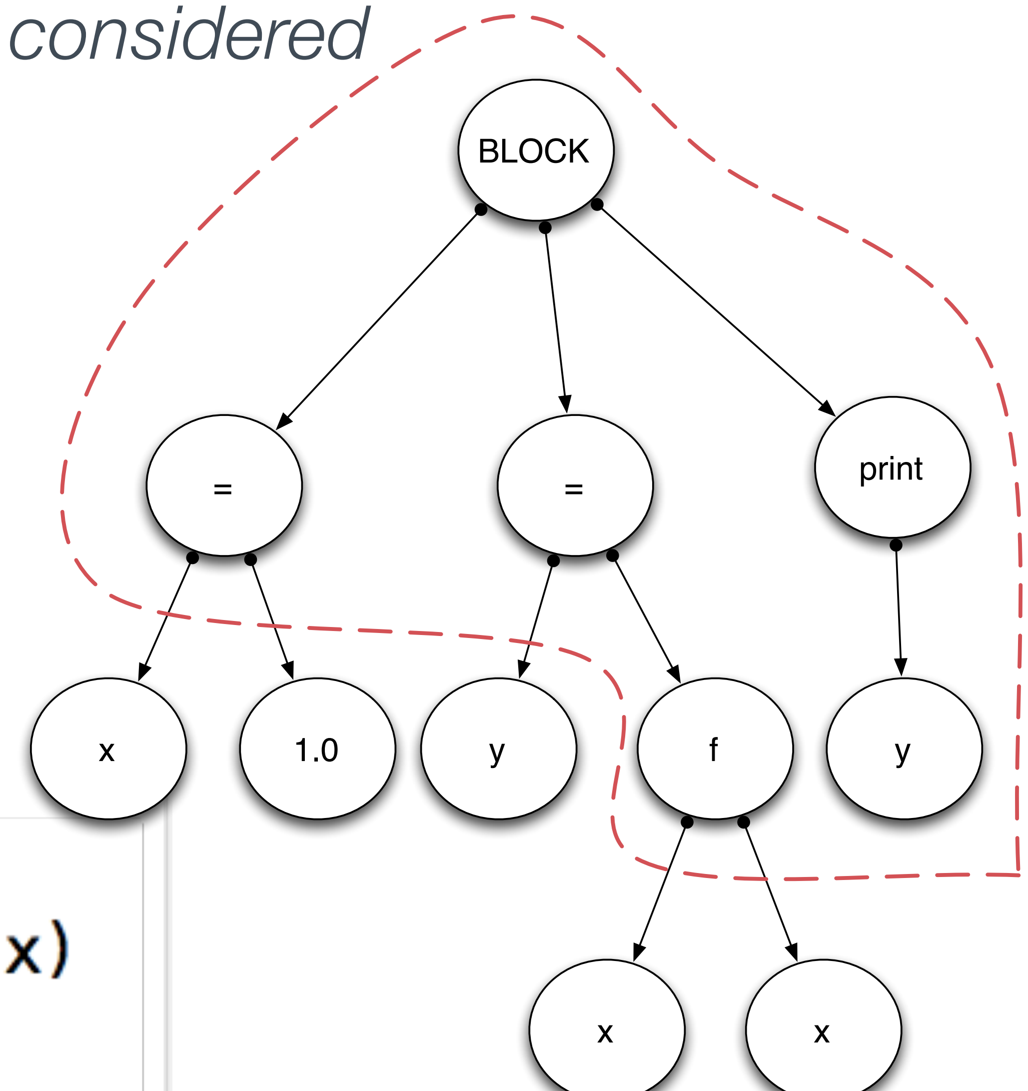
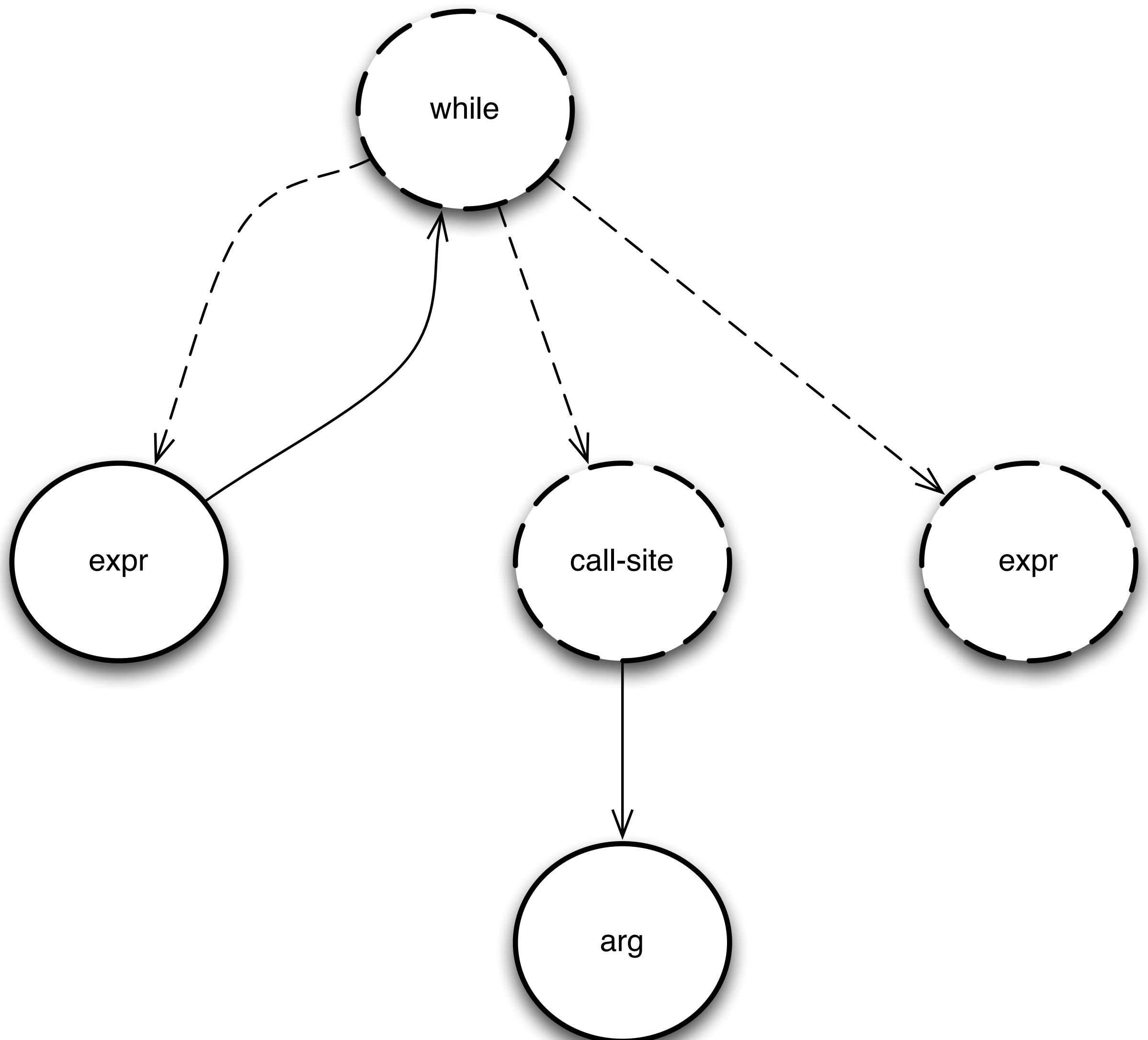
print p
```

```
x = 1.0
y = f(x, x)
print y
```



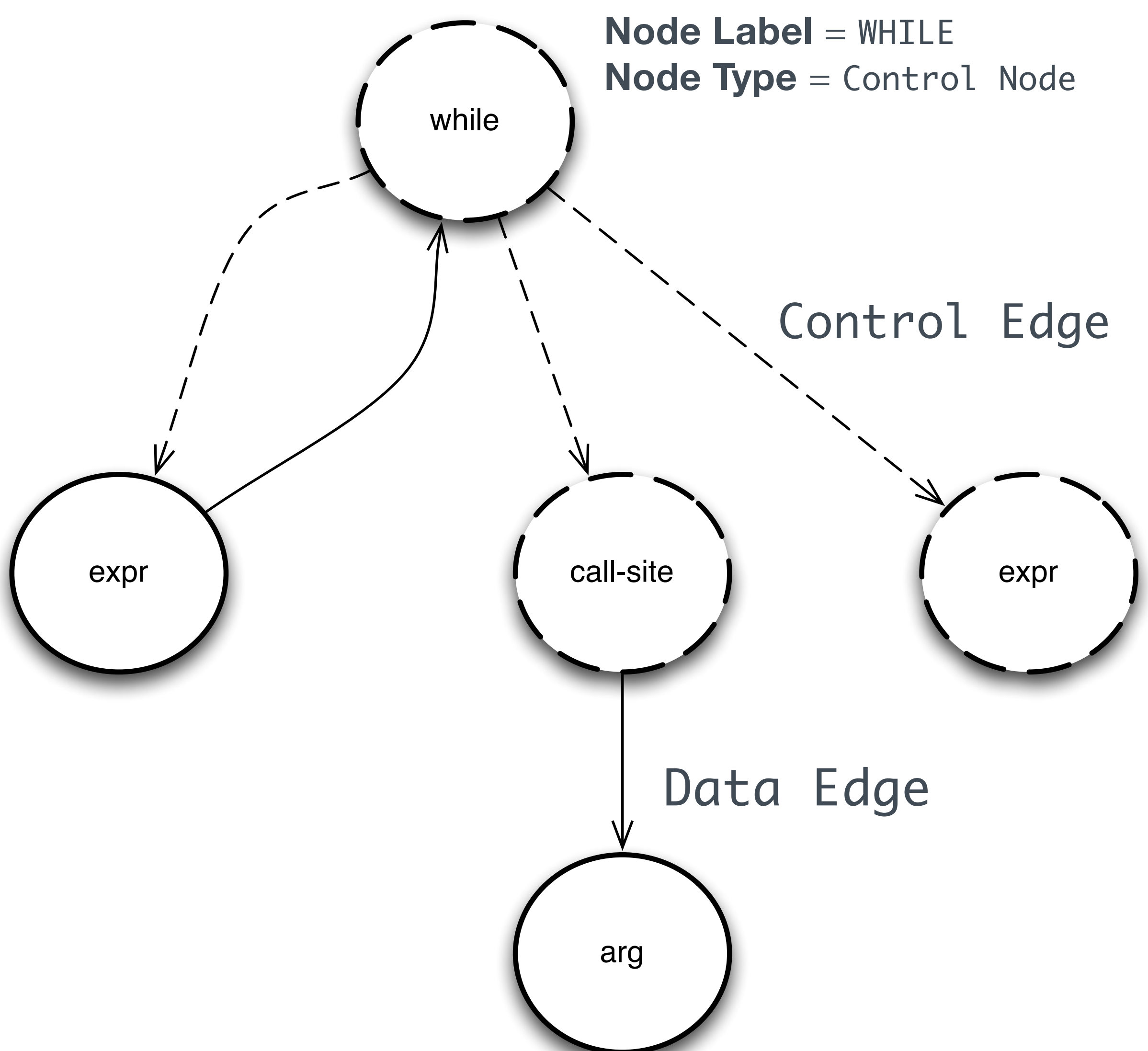
GRAPH KERNELS FOR PDG



- **Features of nodes**:
  - **Node Label**
    - i.e., , `WHILE, CALL-SITE, EXPR, ...`
  - **Node Type**
    - i.e., `Data Node or Control Node`
- **Features of edges:**
  - **Edge Type**
    - i.e., `Data Edge or Control Edge`

KERNELS
FOR CODE STRUCTURES:
PDG

GRAPH KERNELS FOR PDG



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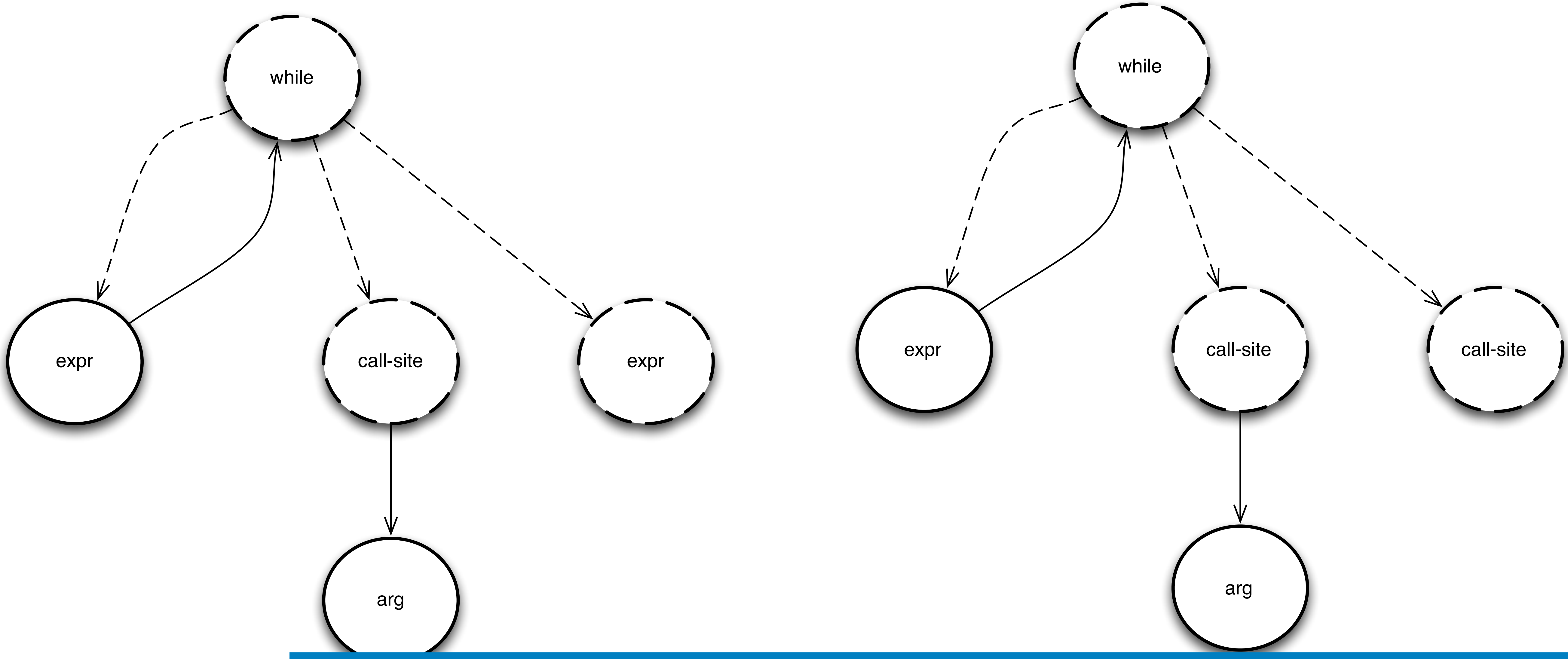
GRAPH KERNELS FOR PDG

- **Goal:** *Identify common subgraphs*
- ***Selectors:*** *Compare nodes to each others and explore the subgraphs of only "compatible" nodes (i.e., Nodes of the same type)*
- ***Context:*** *The subgraph of a node (with paths whose lengths are at most L to avoid loops)*



KERNELS FOR CODE STRUCTURES: **PDG**

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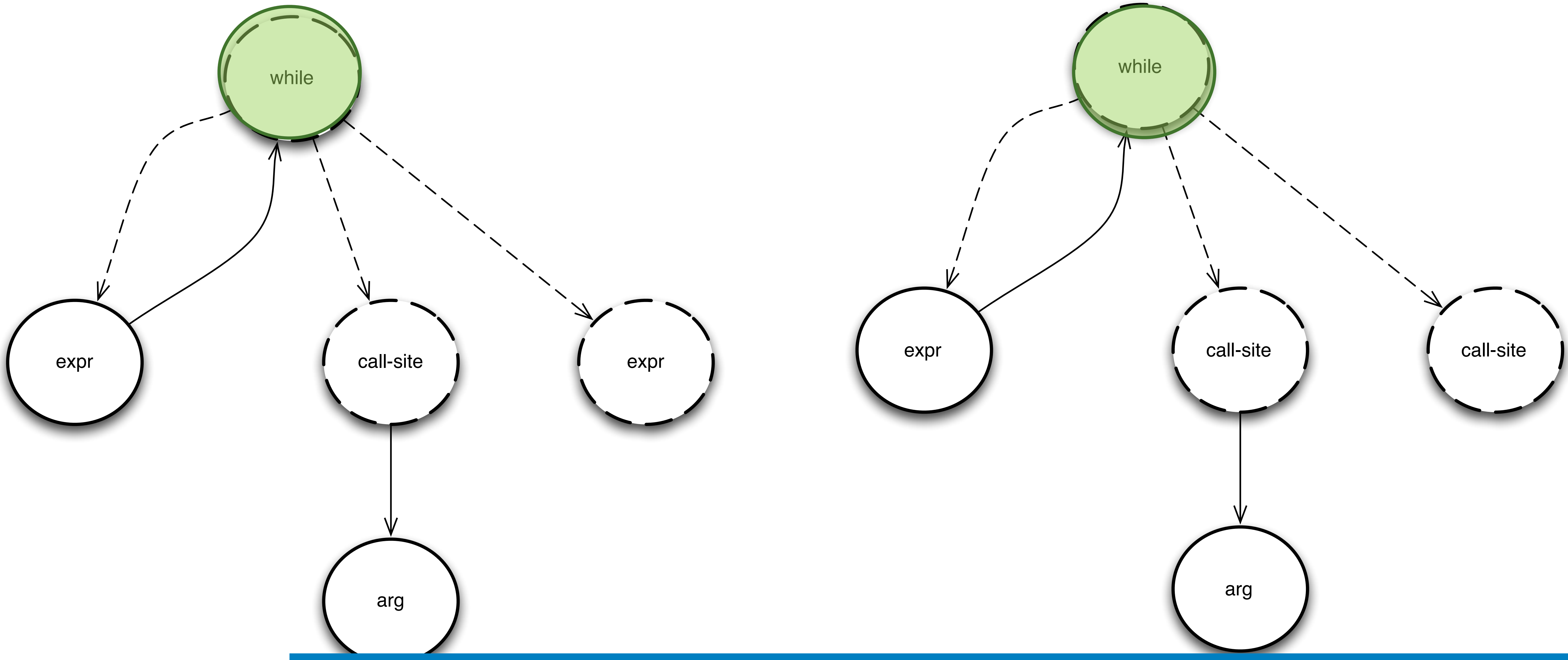

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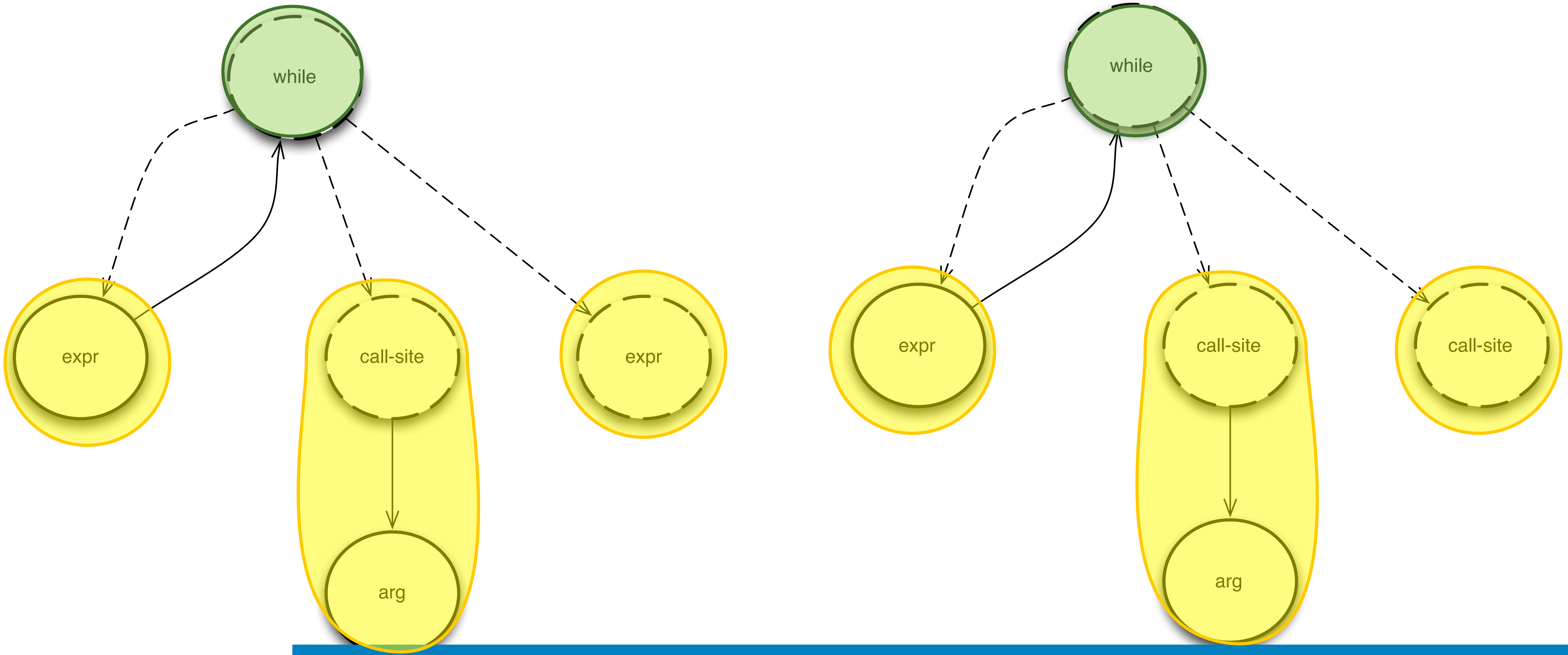

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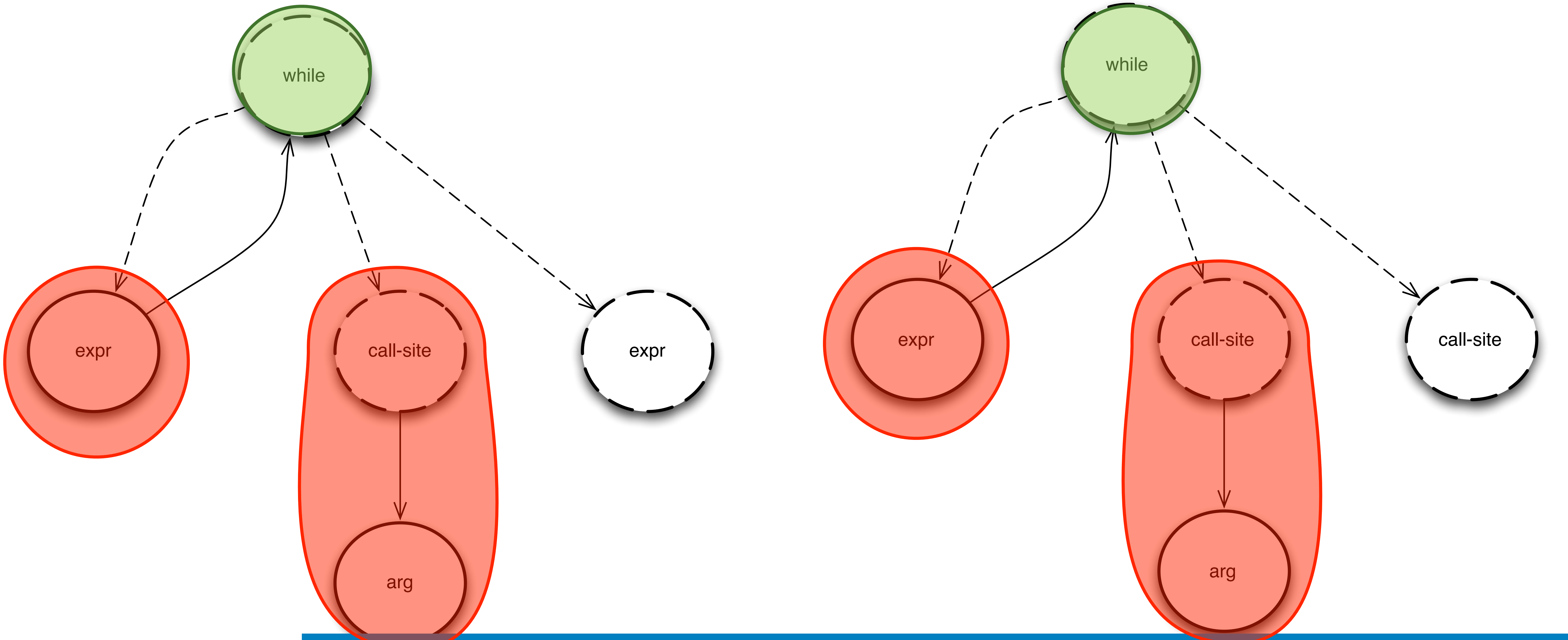

EVALUATION PROTOCOL

- Comparison of results with other two clone detector tools:
  - AST-based Clone detector
  - PDG-based Clone Detector

EVALUATION PROTOCOL

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  - Manual classification of candidate results

EMPIRICAL
EVALUATION

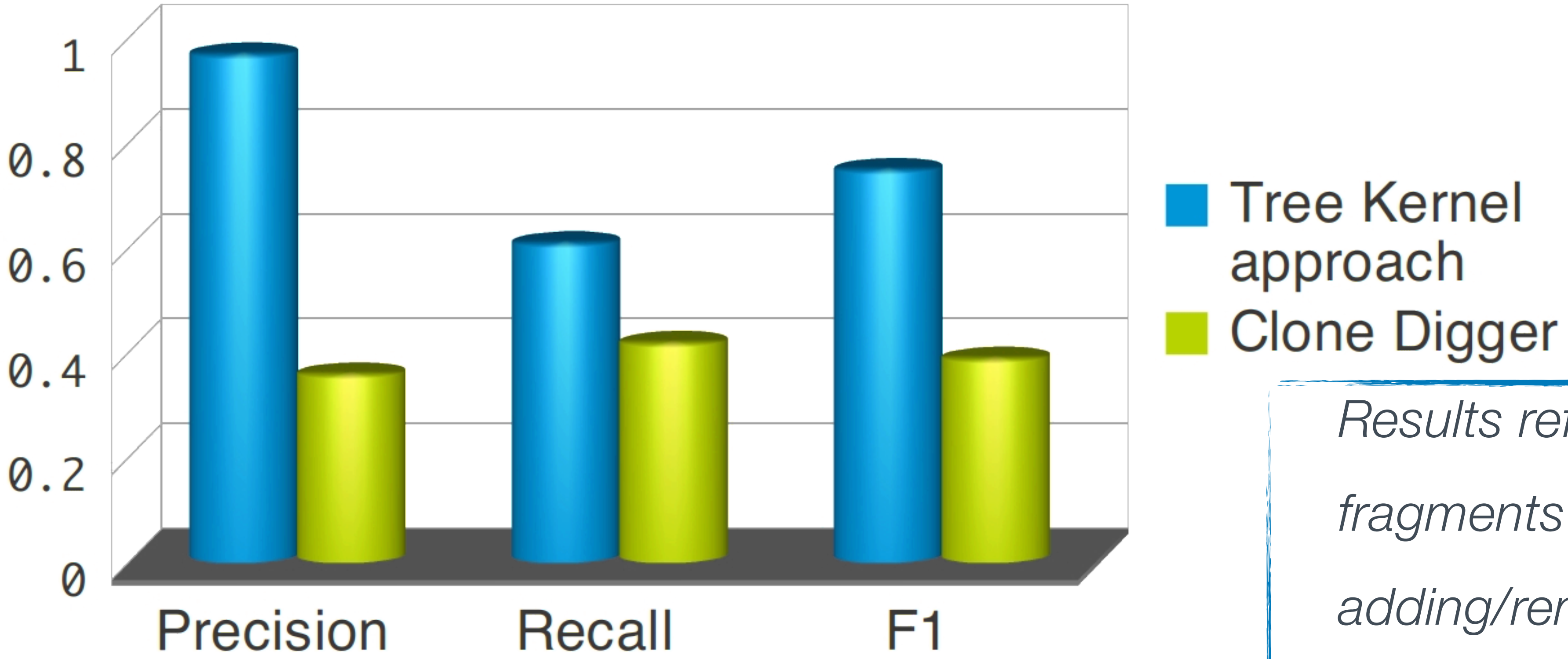
BENCHMARKS AND DATASET

Project	Size (KLOC)	# PDGS
Apache-2.2.14	343	3017
Python-2.5.1	435	5091

- Comparison with another Graph-based clone detector
  - MeCC (ICSE2011)
- **Baseline** Dataset
  - Results provided by MeCC
- **Extended** Dataset
  - Extension of Clones results by manual evaluation of candidate clones
    - Agreement rate calculation between the evaluators

EMPIRICAL EVALUATION OF TREE KERNEL FOR AST

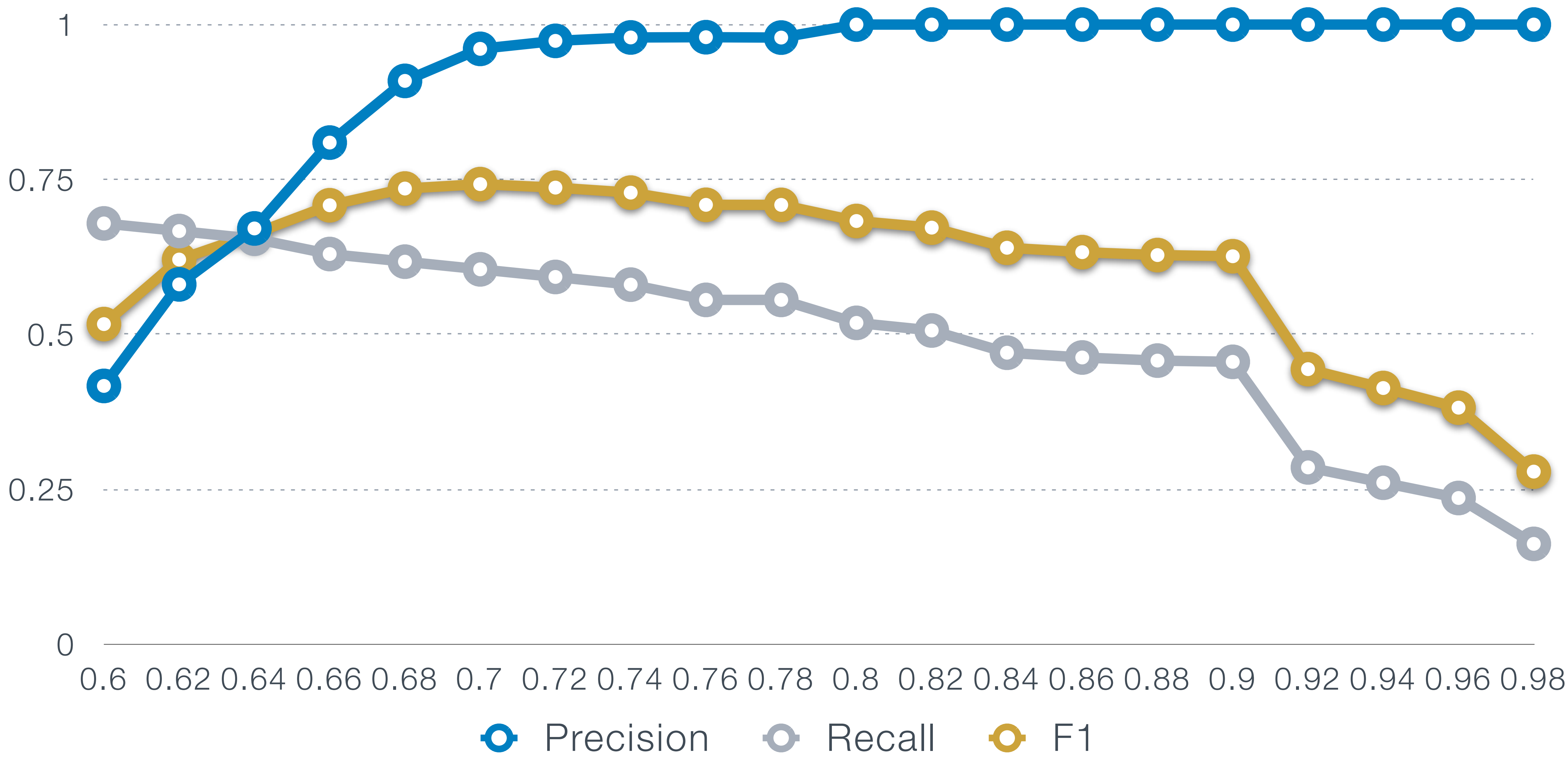
- Comparison with another (pure) AST-based clone detector
  - Clone Digger http://clonedigger.sourceforge.net/
- Comparison on a system with randomly seeded clones



Results refer to clones where code fragments have been modified by adding/removing or changing code statements

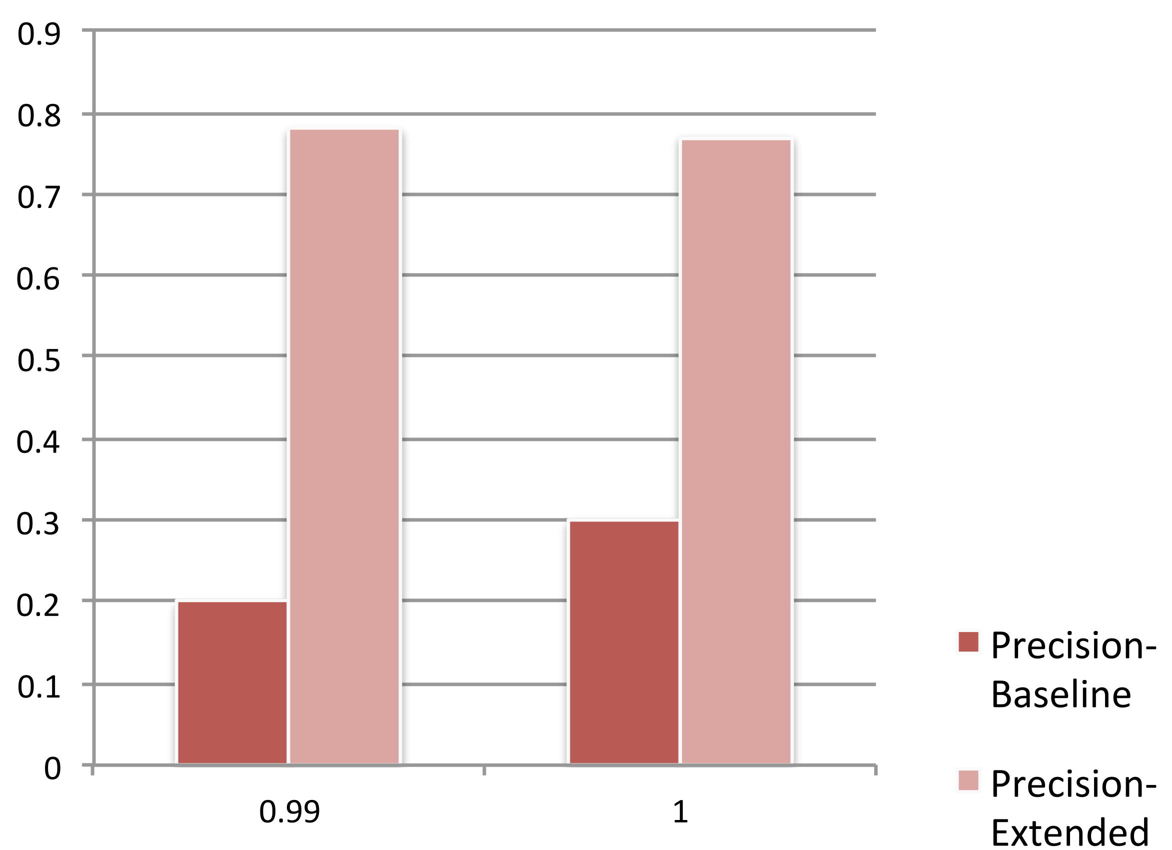
PRECISION, RECALL AND F1 PLOT

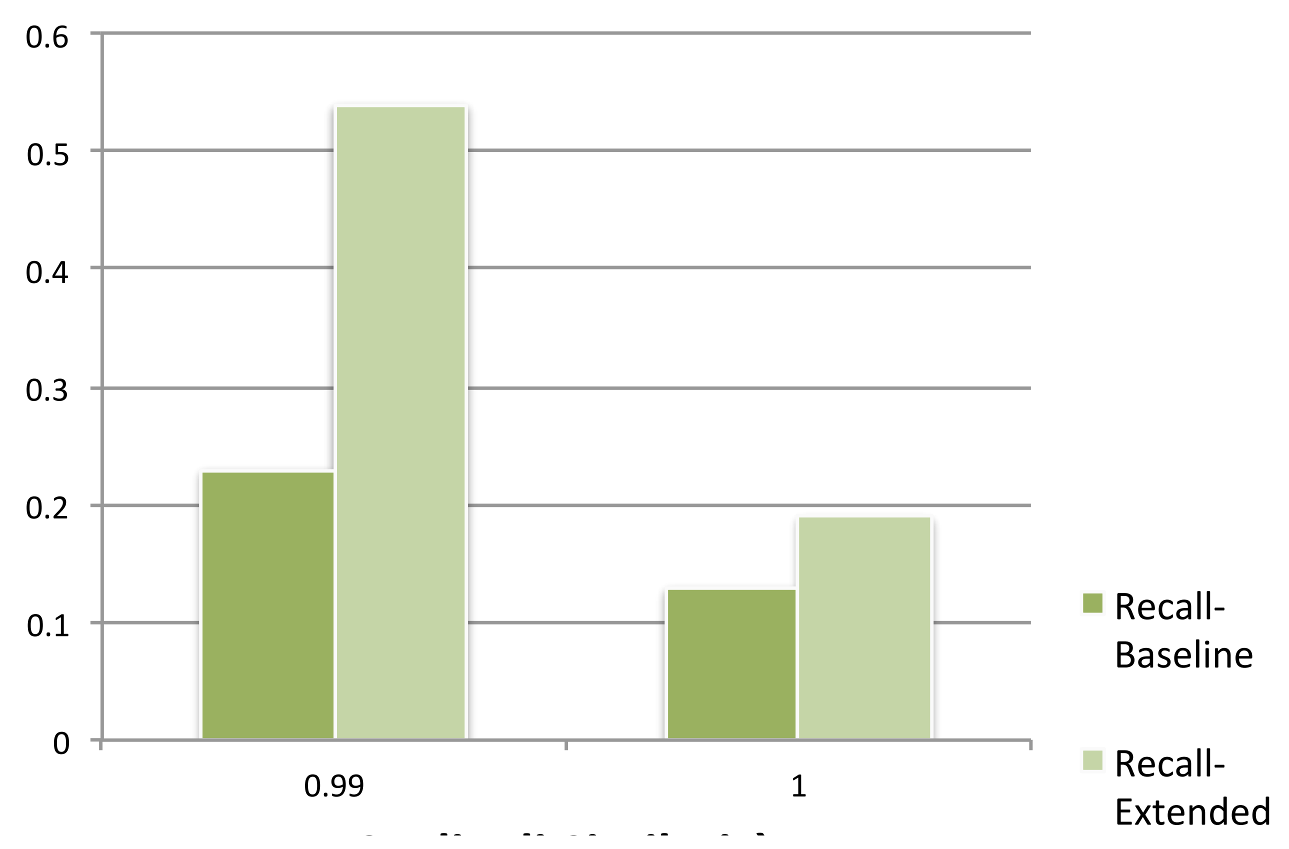
Clone results with different similarity thresholds



RESULTS WITH APACHE 2.2.14

Threshold	#Clones in the Baseline	#Clones in the Extended Dataset
1.00	874	1089
0.99	874	1514

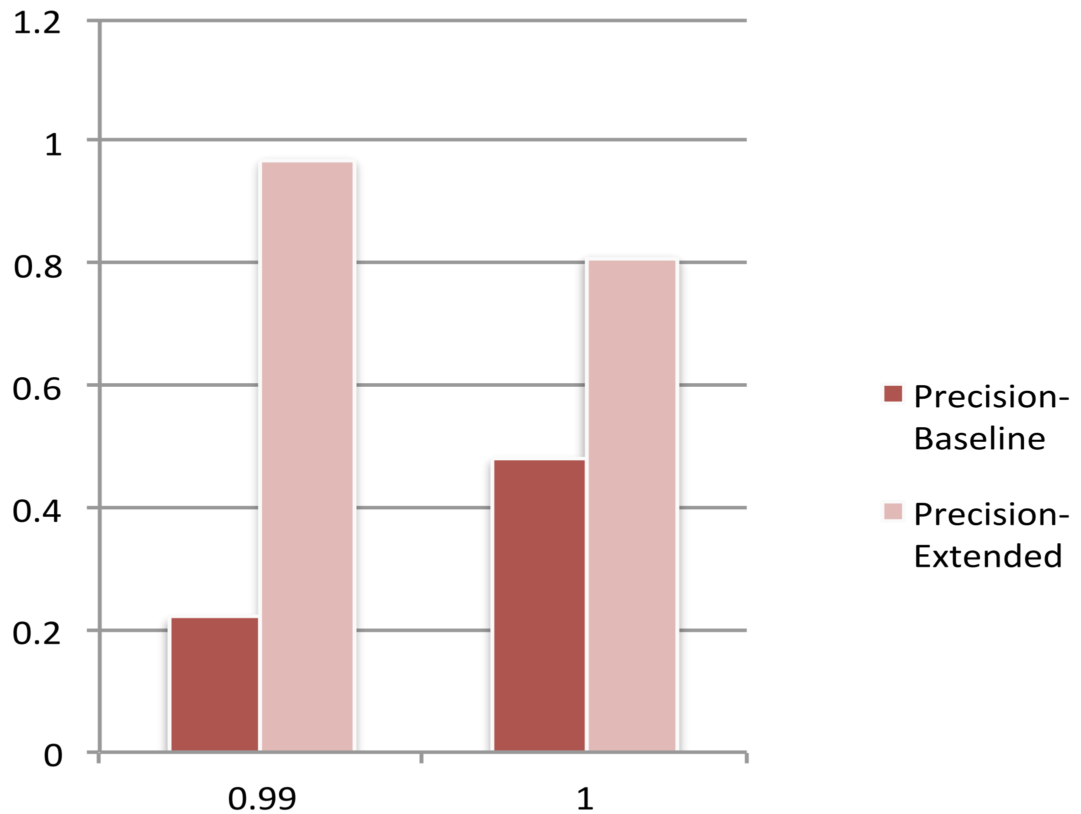


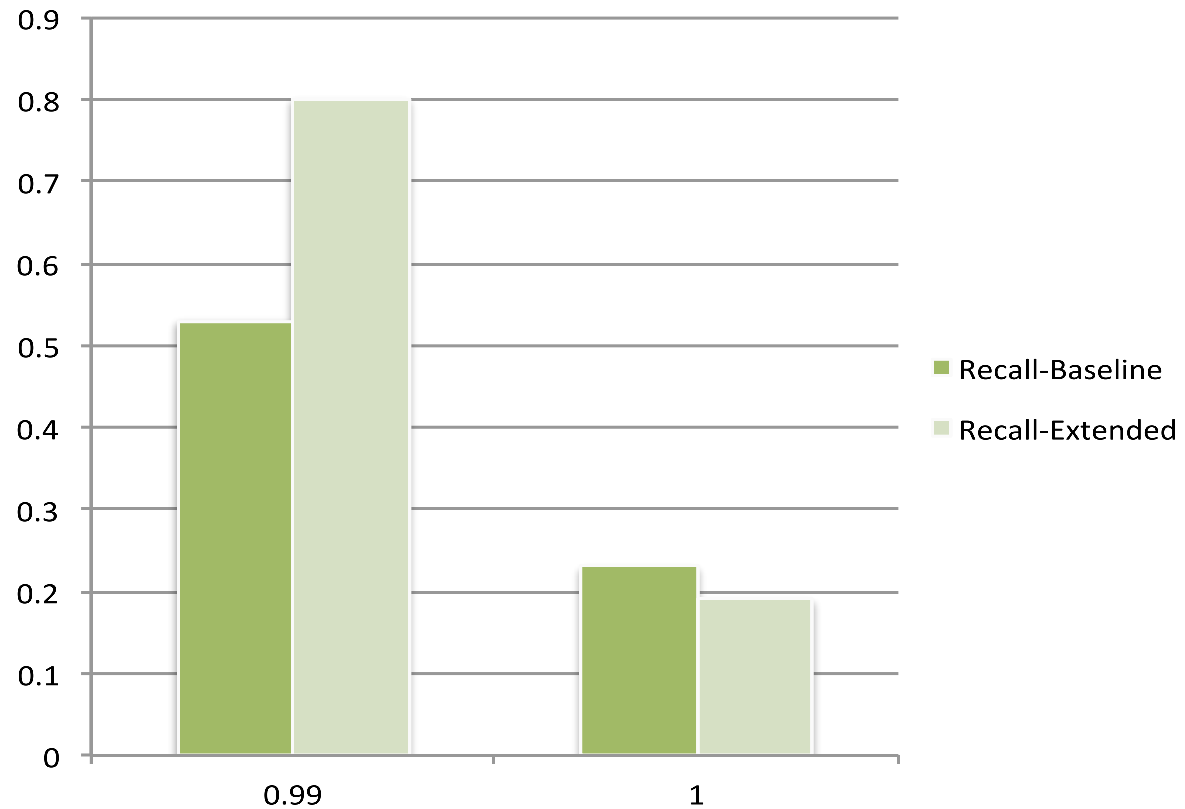


EVALUATION
GRAPH KERNELS FOR PDG

RESULTS WITH PYTHON 2.5.2

Threshold	#Clones in the Baseline	#Clones in the Extended Dataset
1.00	858	1066
0.99	858	2119





CHALLENGES AND OPPORTUNITIES

- Learning Kernel Functions from Data Set
  - Kernel Methods **advantages**:
    - flexible solution to be tailored to specific domain
    - efficient solution easy to parallelize
    - combinations of multiple kernels
  - Provide a publicly available data set

THANK YOU

FOR YOUR KIND ATTENTION