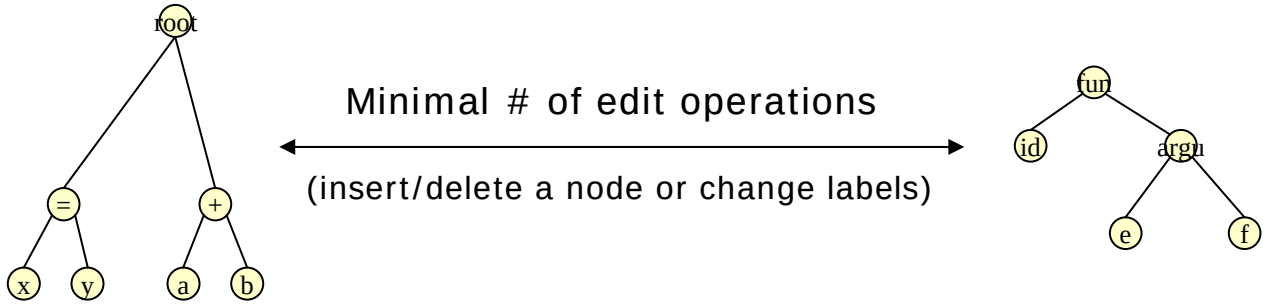
Tree Similarity and Code Clones

- Well defined tree similarity problem
  - Tree editing distance $\delta(T_1, T_2)$:



  - T_1 and T_2 are *σ-similar* if $\delta(T_1, T_2) < \sigma$

- Code clones based on δ

```
……
for ( int i = 0; i < n; i++ )
   x[i] = 0;
for ( int i = 0; i < n; i++ )
   x[i] = 0;
……
```

Code$_1$

clone pair, if $\delta(T_1, T_2) < \sigma$

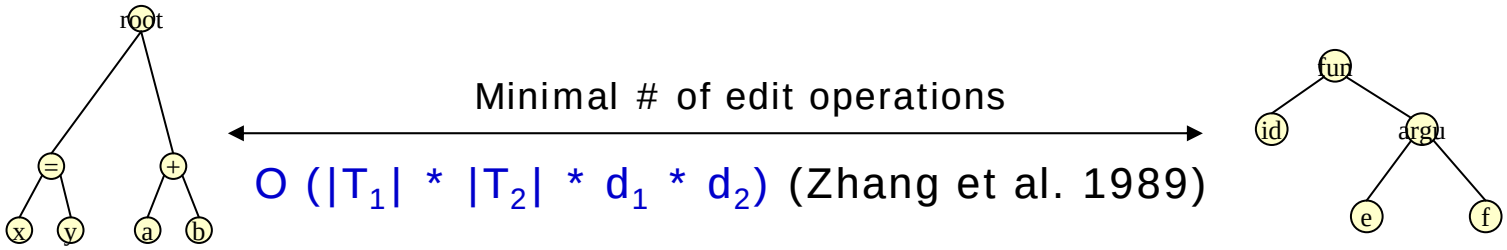
```
……
for ( int i = 0; i < n; i++ )
   y[i] = "";
for ( int i = 0; i < n; i++ )
   y[i] = "";
……
```

Code$_2$

Not Scalable

A clone detection directly based on the definition would not scale:

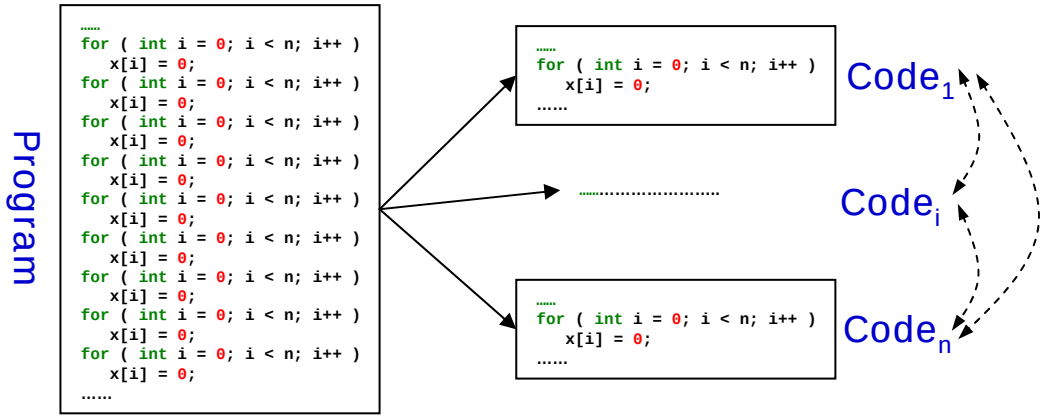
- Computing tree editing distance is expensive



$O(|T_1| * |T_2| * d_1 * d_2)$ (Zhang et al. 1989)

where d_i is the minimum of the depth of T_i and the number of leaves of T_i

- Need to compare many pairs of subtrees

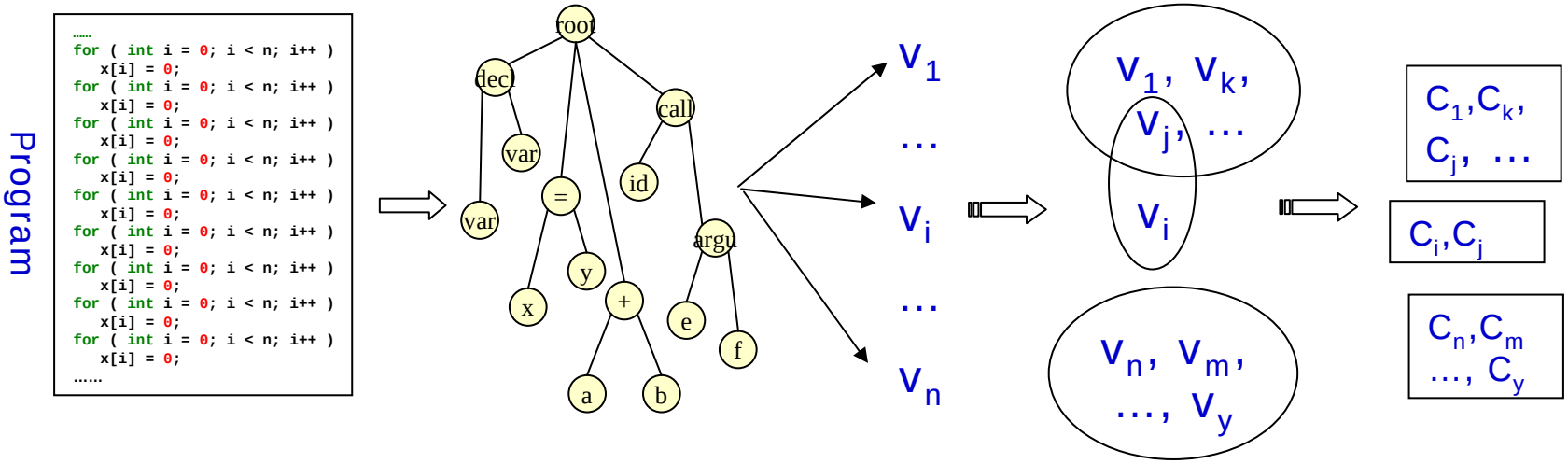


Quadratic # of Tree Comparison

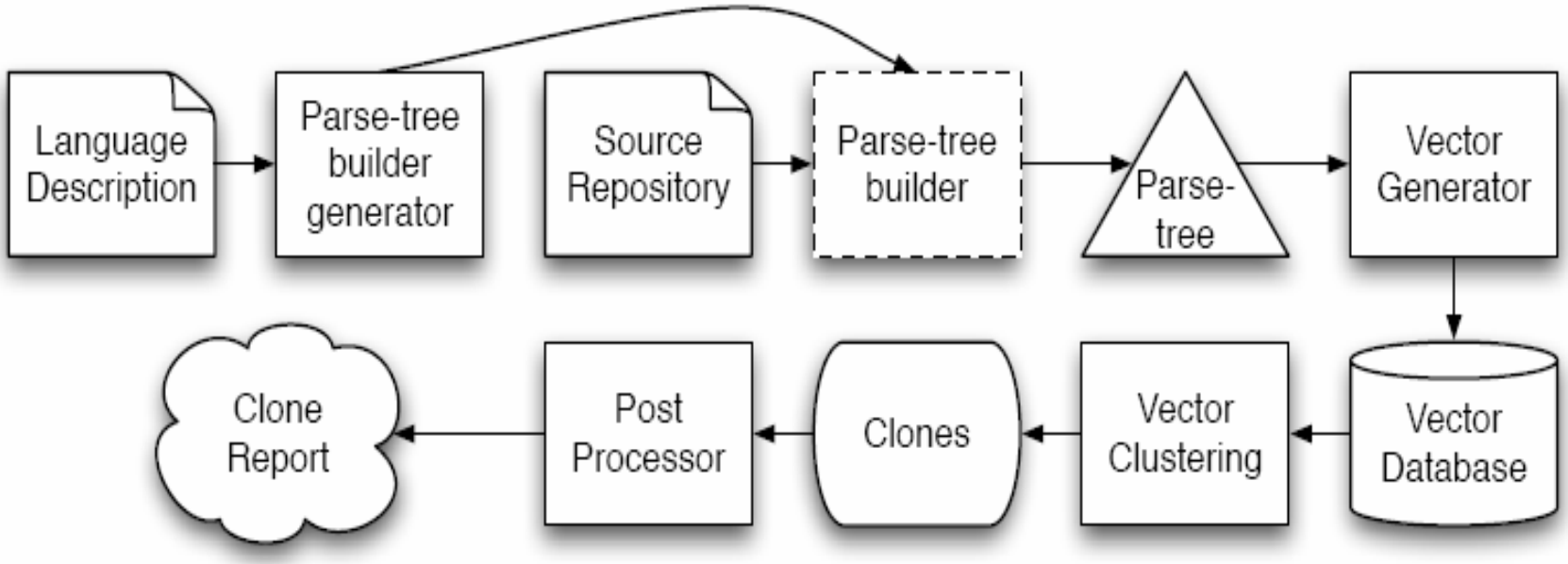
The Idea – Numerical Vectors

- Numerical vectors are much easier to compare than trees
  - Suppose $v_1 = \langle x_1, \ldots, x_n \rangle$ and $v_2 = \langle y_1, \ldots, y_n \rangle$
  - Hamming distance (or the l_1 *norm*): $\mathcal{H}(v_1, v_2) = \sum^{n} |x_i - y_i|$
  - Euclidean distance (or the l_2 *norm*): $\mathcal{D}(v_1, v_2) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$

- Characterize parse trees as numerical vectors
  - Cluster vectors based on numerical distances
  - Code corresponding to vectors within a same cluster are clones



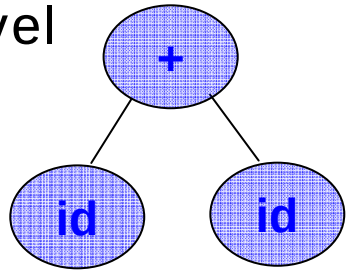
Deckard's High Level Architecture



Characteristic Vectors for Trees

Definitions

- *q-level atomic patterns*
  - Labeled complete binary trees of height q
  - E.g., 2-level



  - At most $|L|^{2^q-1}$ patterns, where L is the set of labels

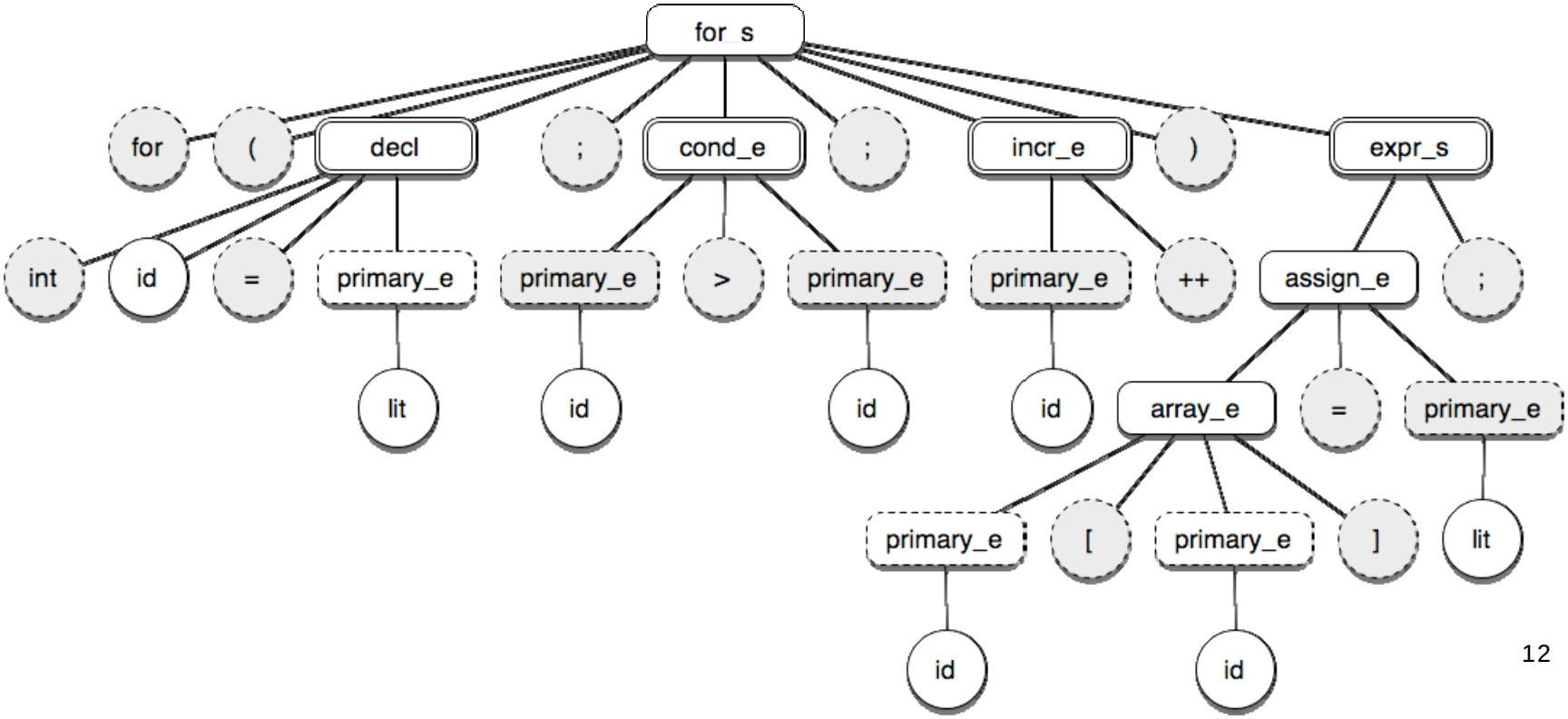
- *q-level vector* for a tree or tree-forest T
  - <b_1, …, b_k>, where $k \leq |L|^{2^q-1}$
  - Each b_i counts # of i-th pattern in T

An Sample Characteristic Vector

```
for ( int i = 0; i < n; i++ )
   x[i] = 0;
```

1-level patterns:

<id, lit, assign_e, incr_e, array_e, cond_e, expr_s, decl, for_s>



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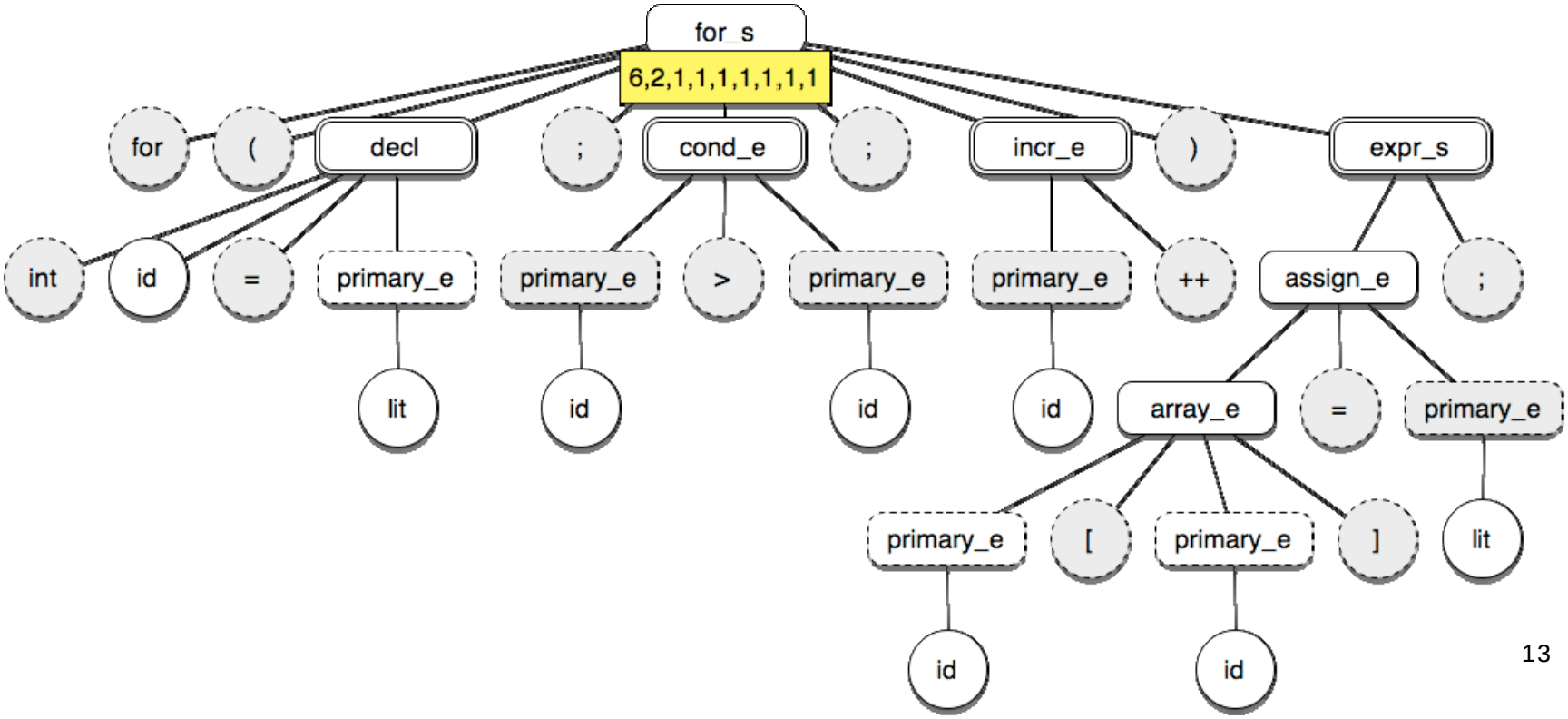
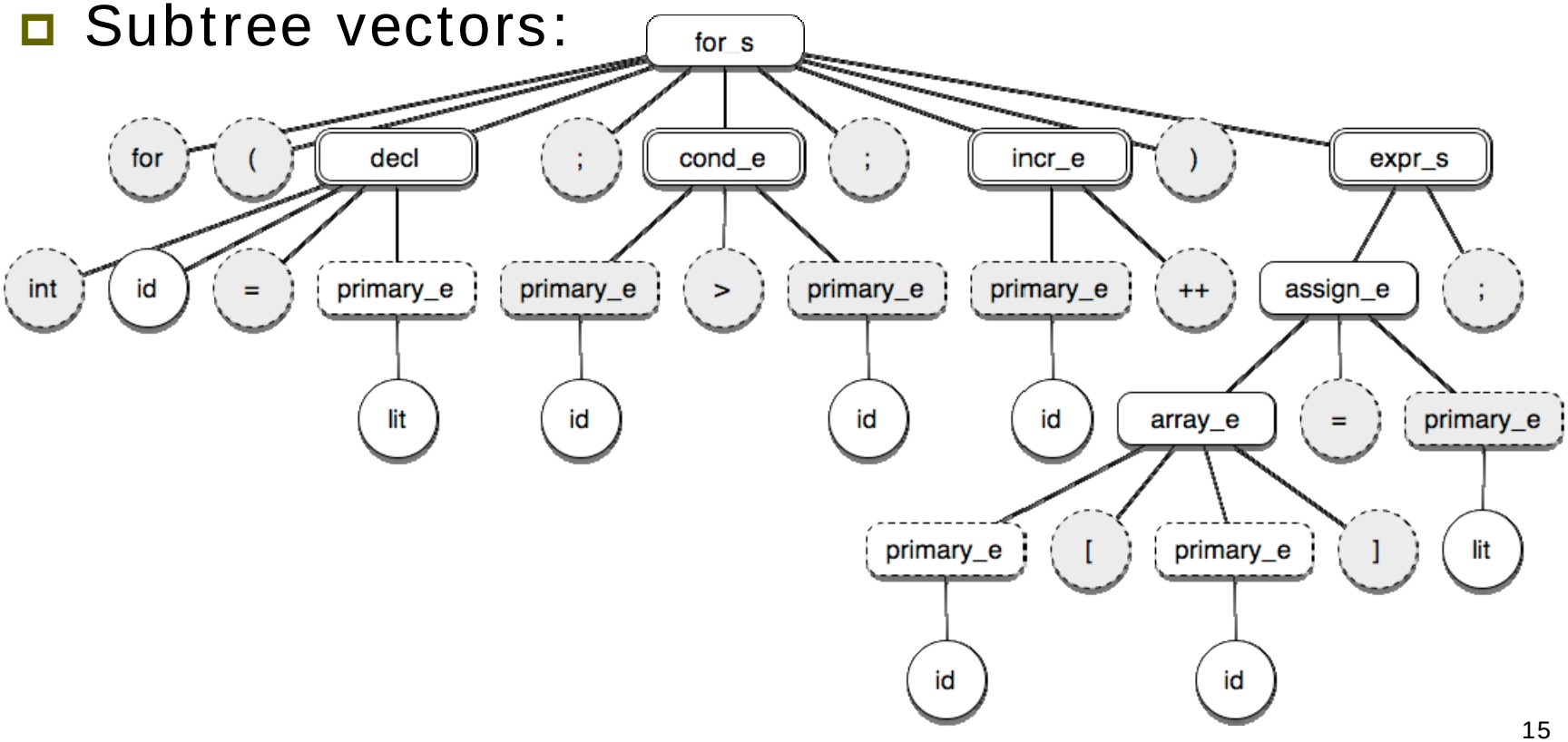


Map Trees to Numerical Vectors (1)

```
for ( int i = 0; i < n; i++ )
   x[i] = 0;
```

<id, lit, assign_e, incr_e, array_e, cond_e, expr_s, decl, for_s>

- Subtree vectors:



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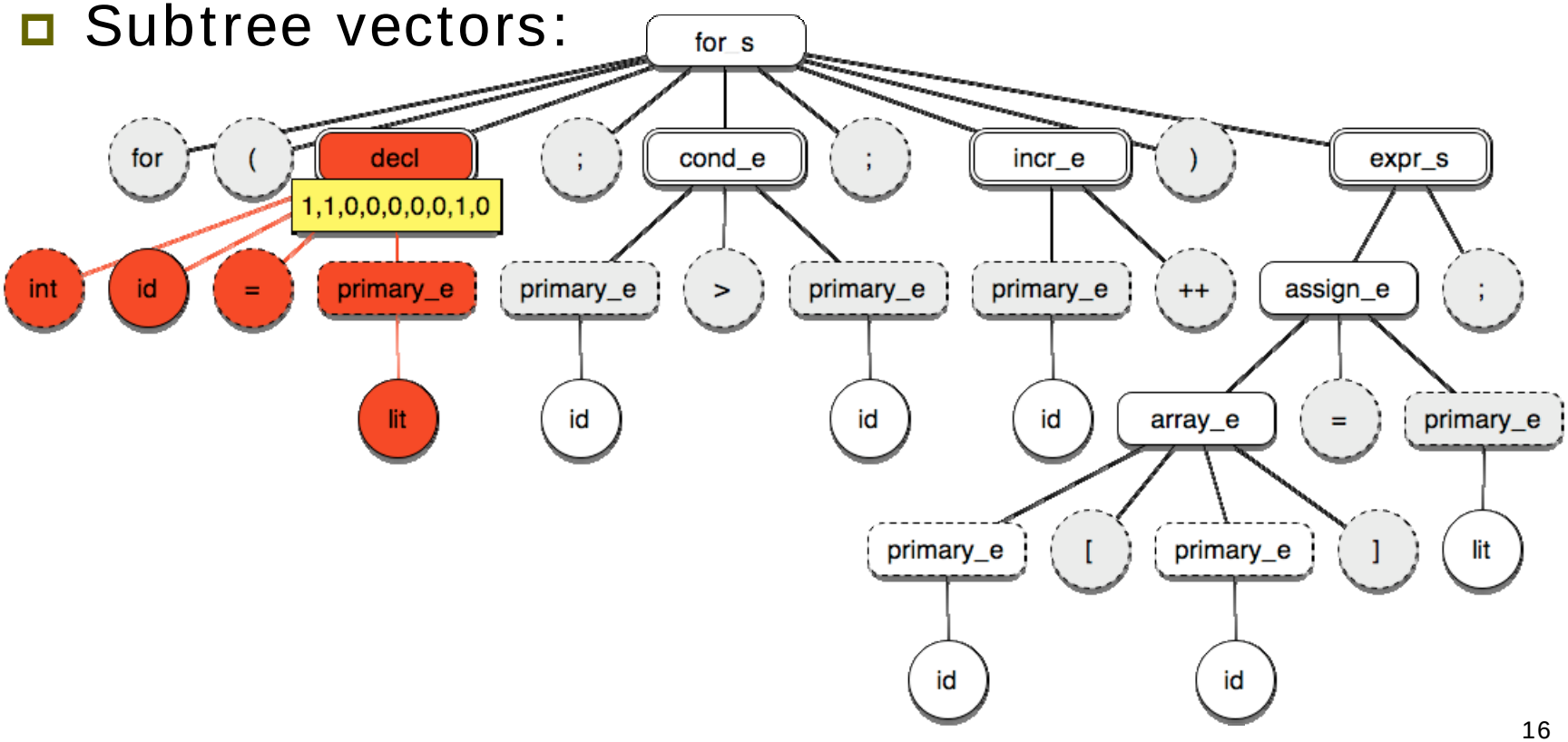

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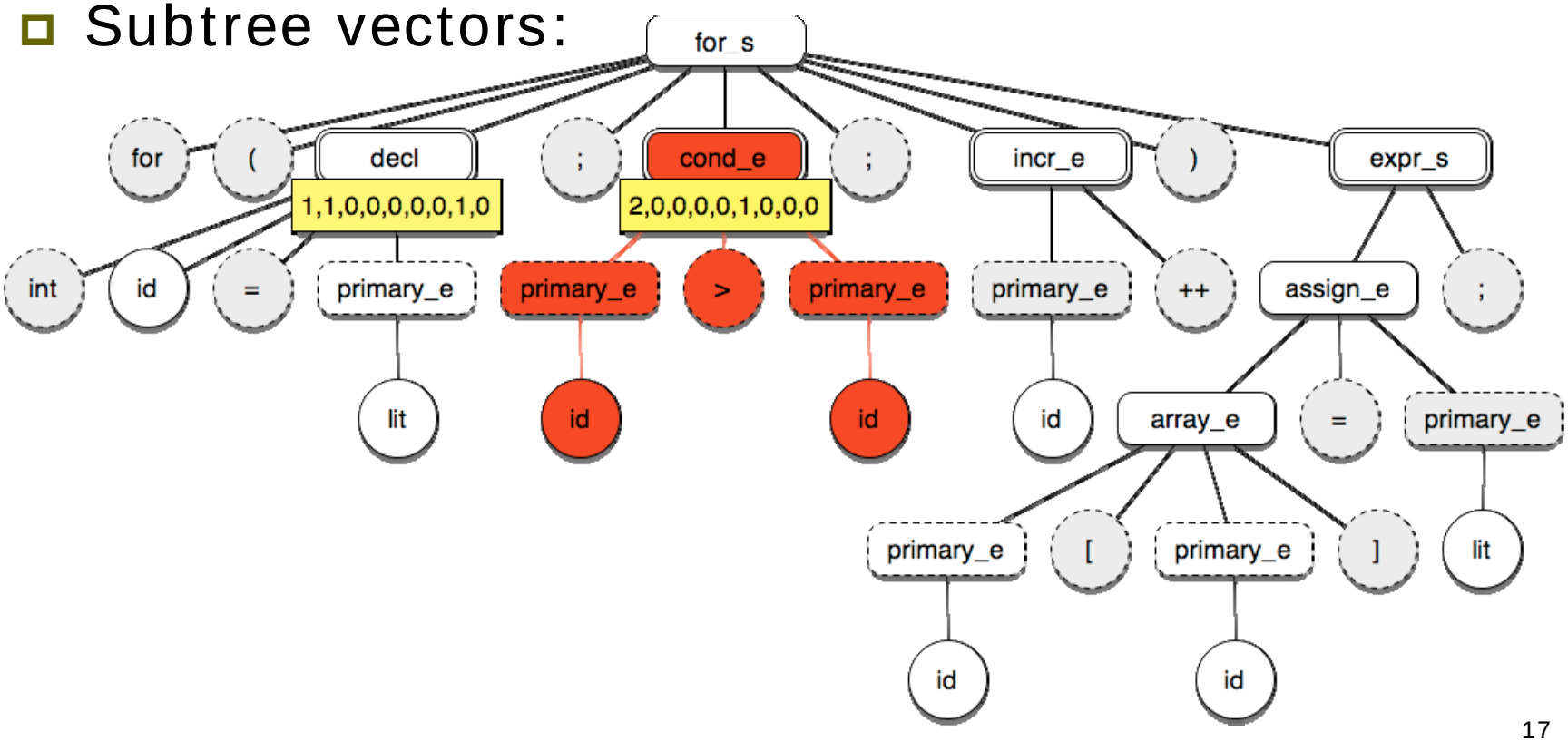

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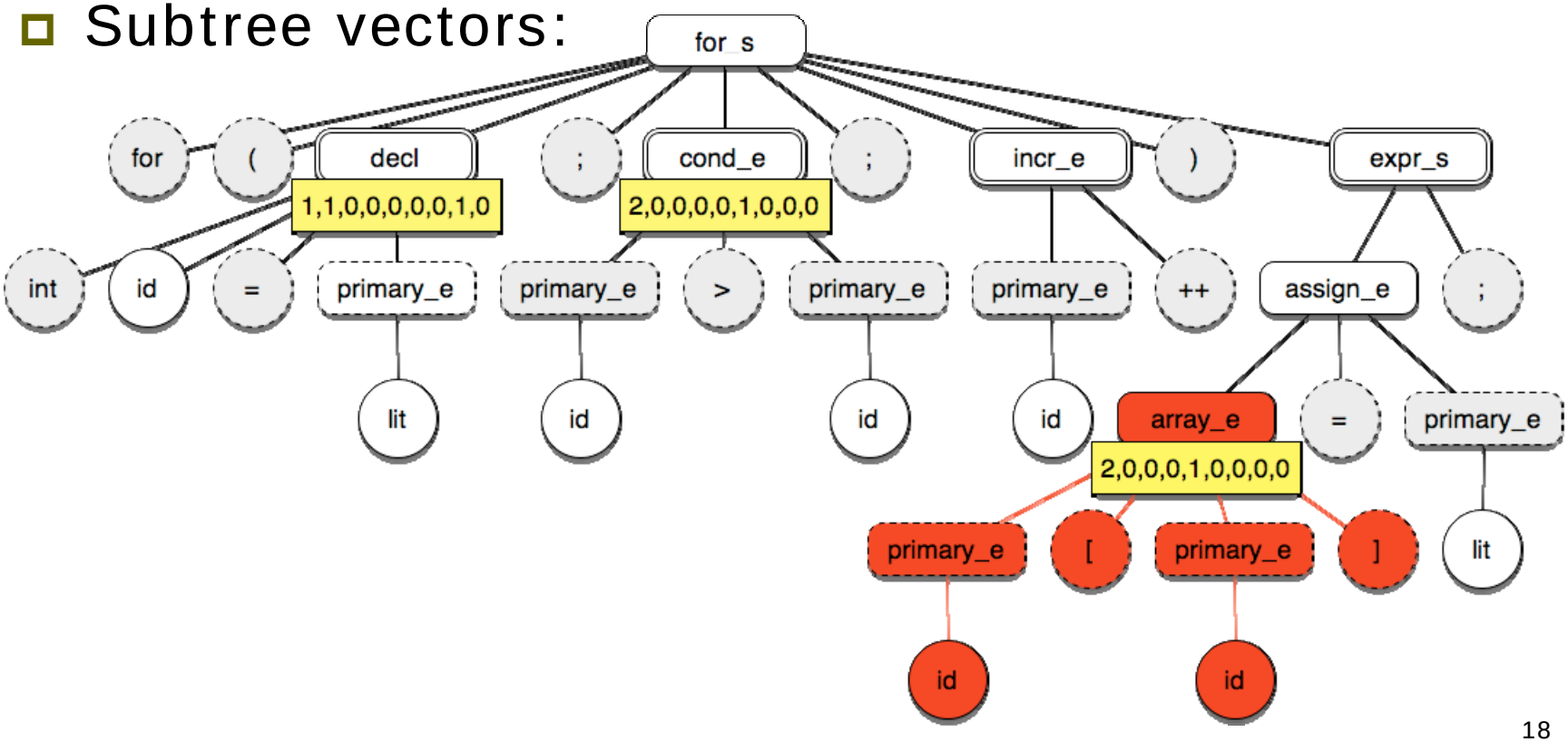

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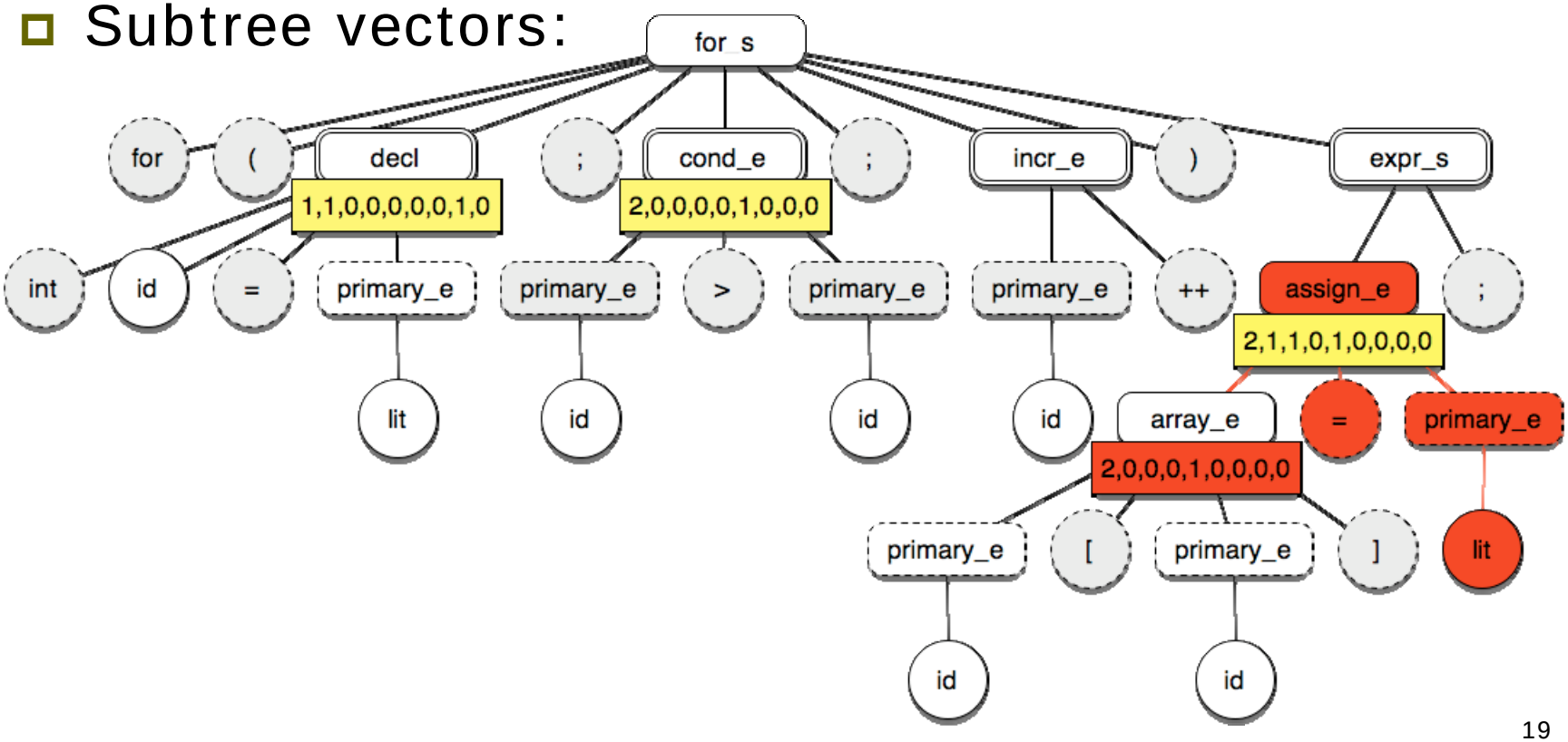

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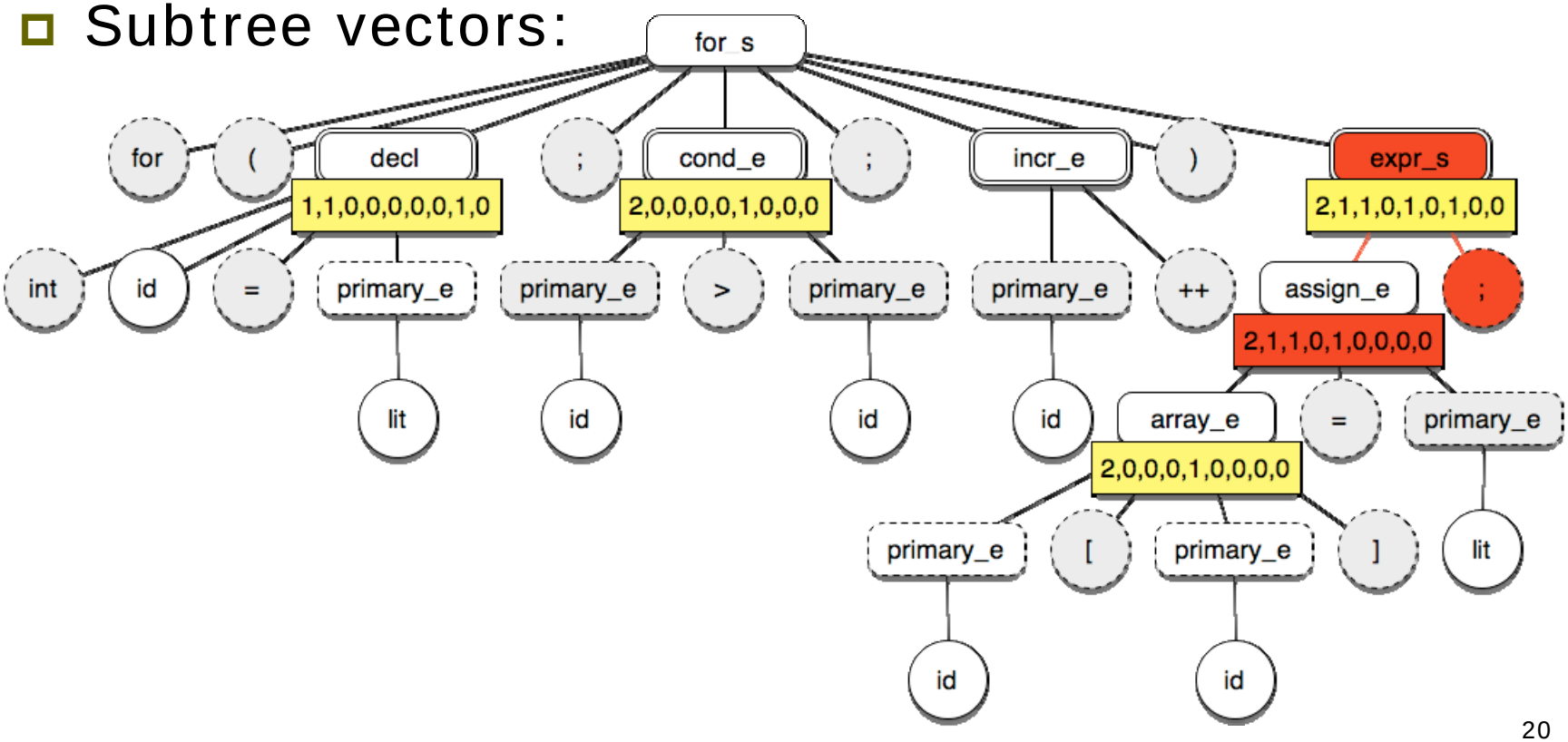

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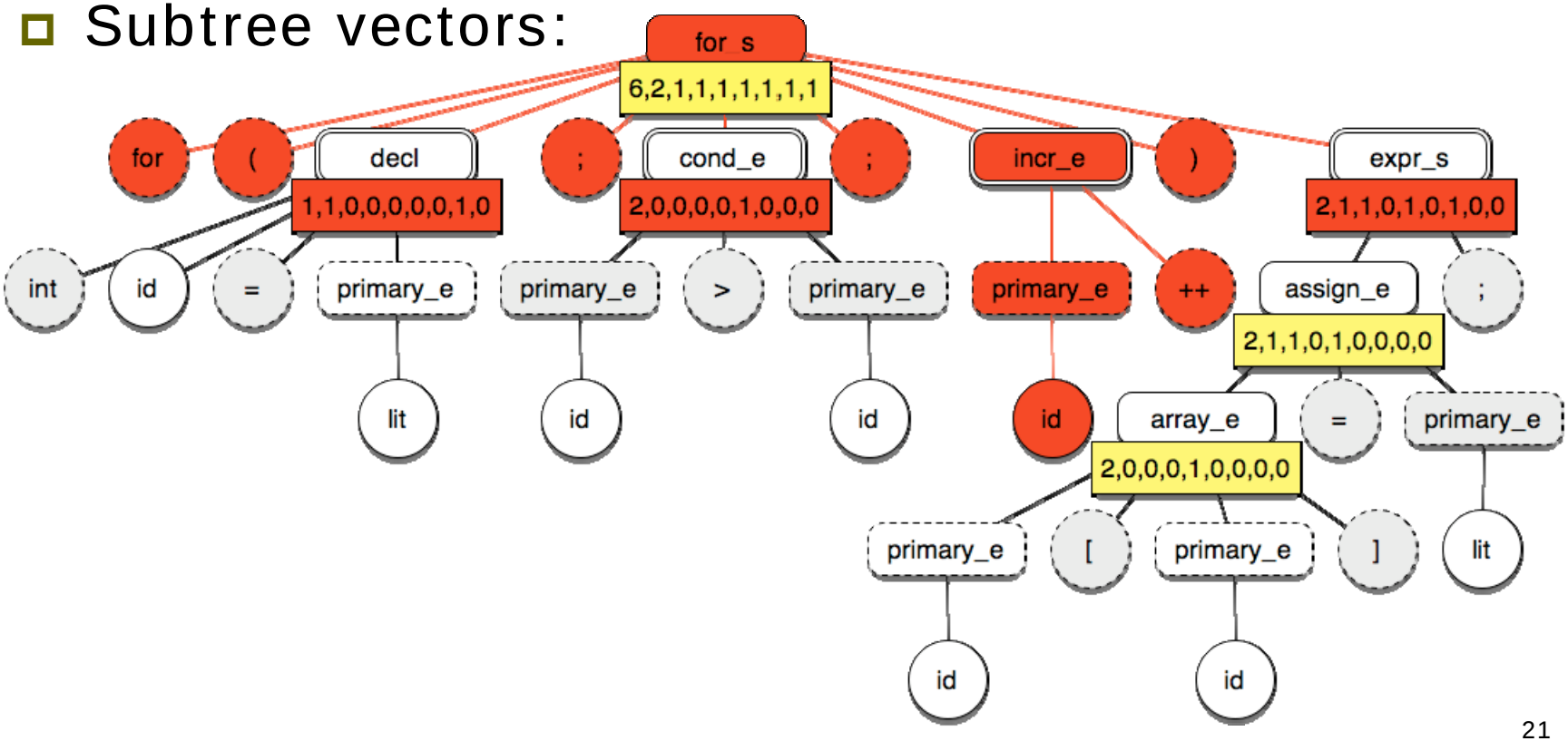

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```

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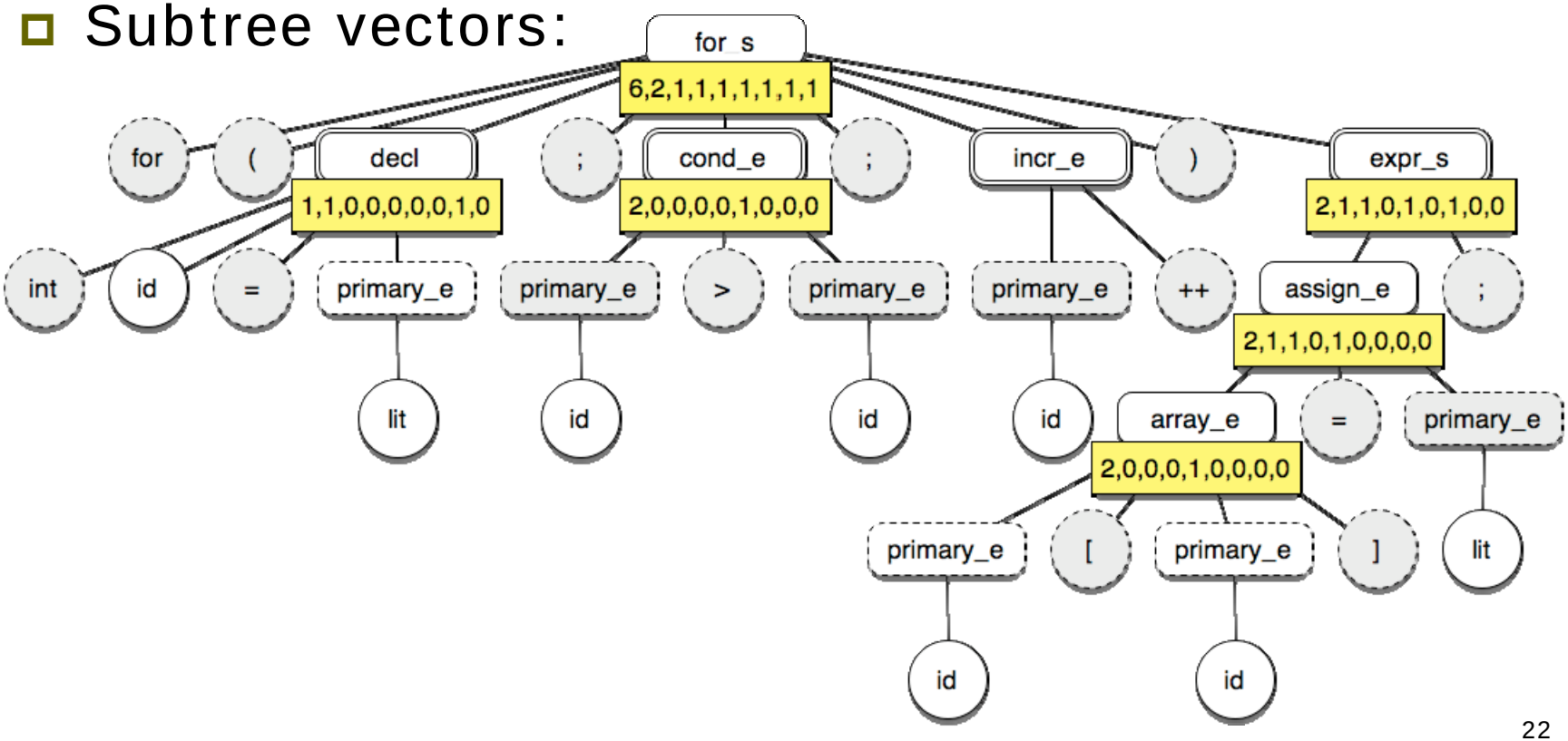
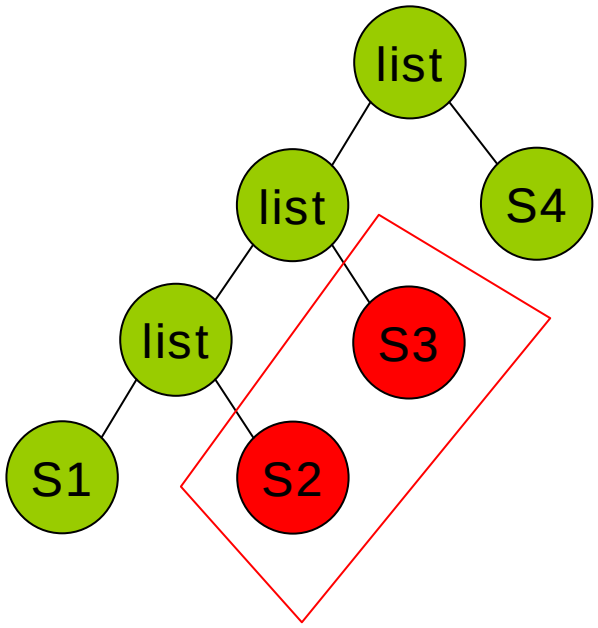
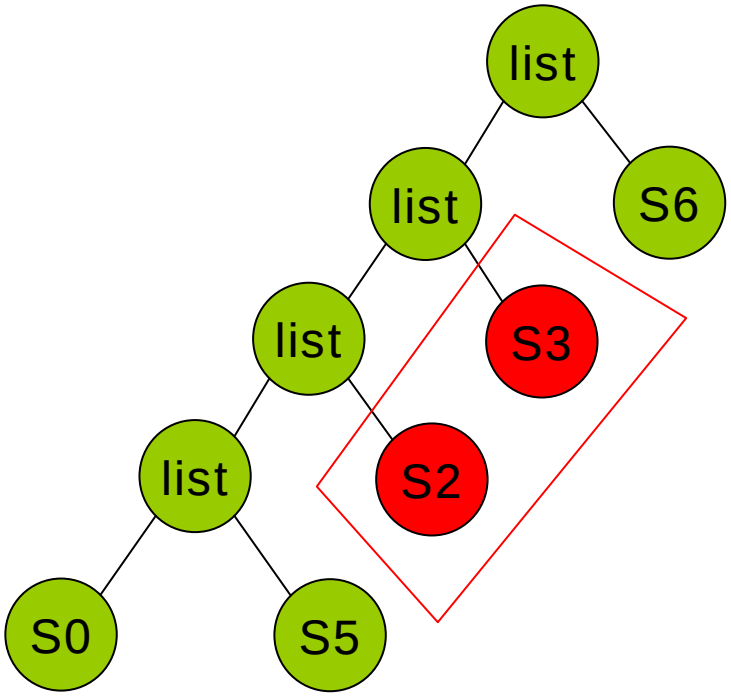


Map Trees to Numerical Vectors (2)

- Forest vectors
  - For sequences of program elements
  - Why needed?
    - S1; S2; S3; S4;
    - S0; S5; S2; S3; S6





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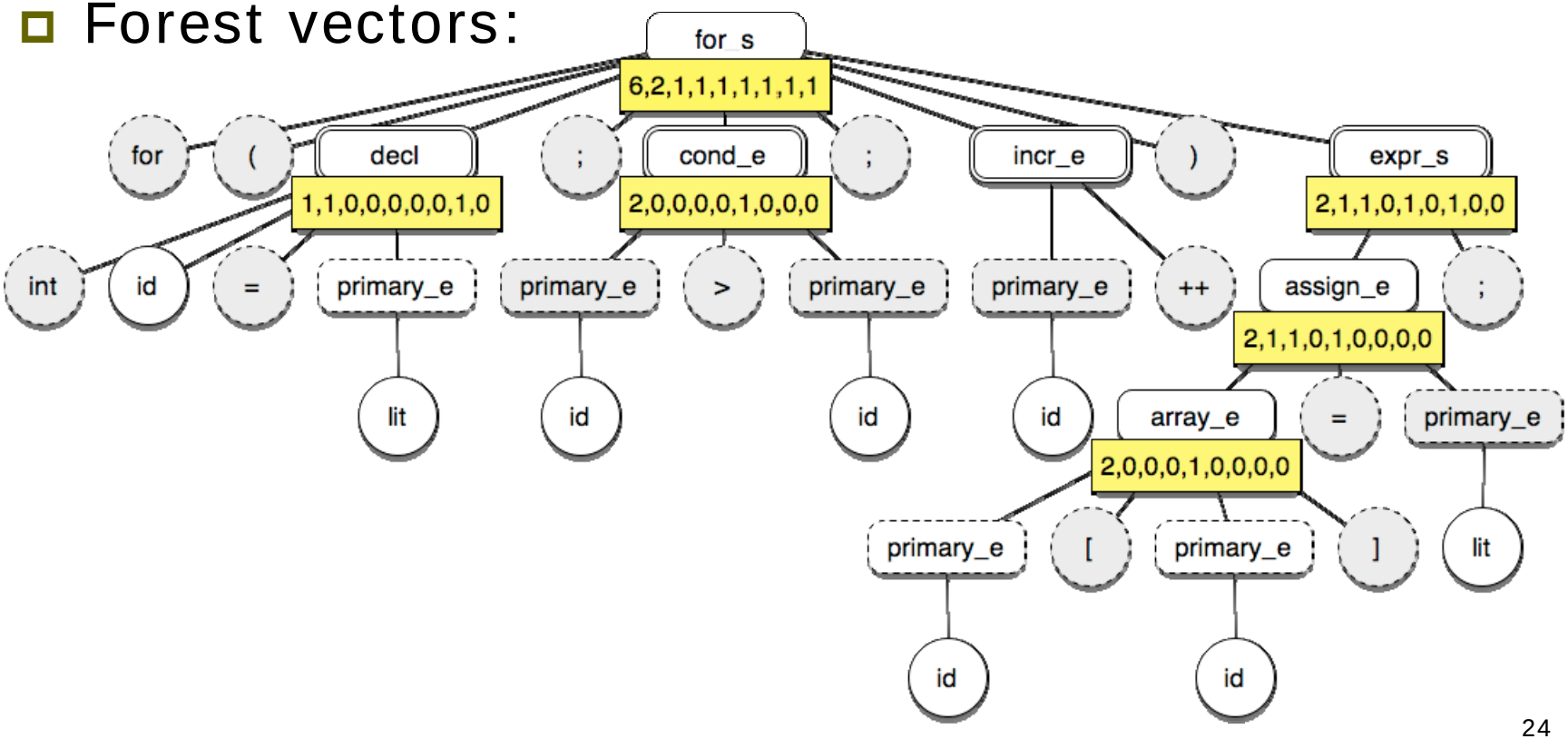

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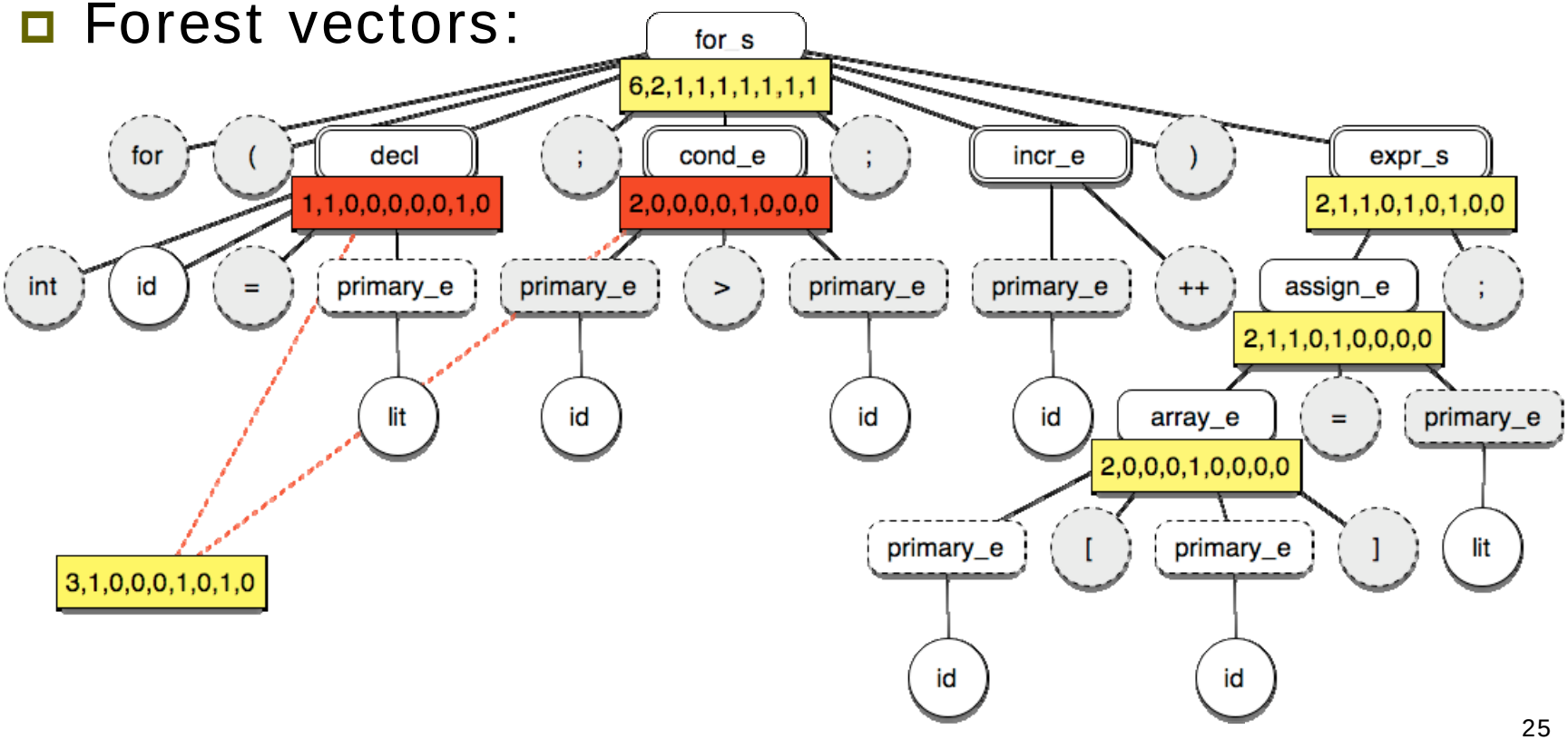
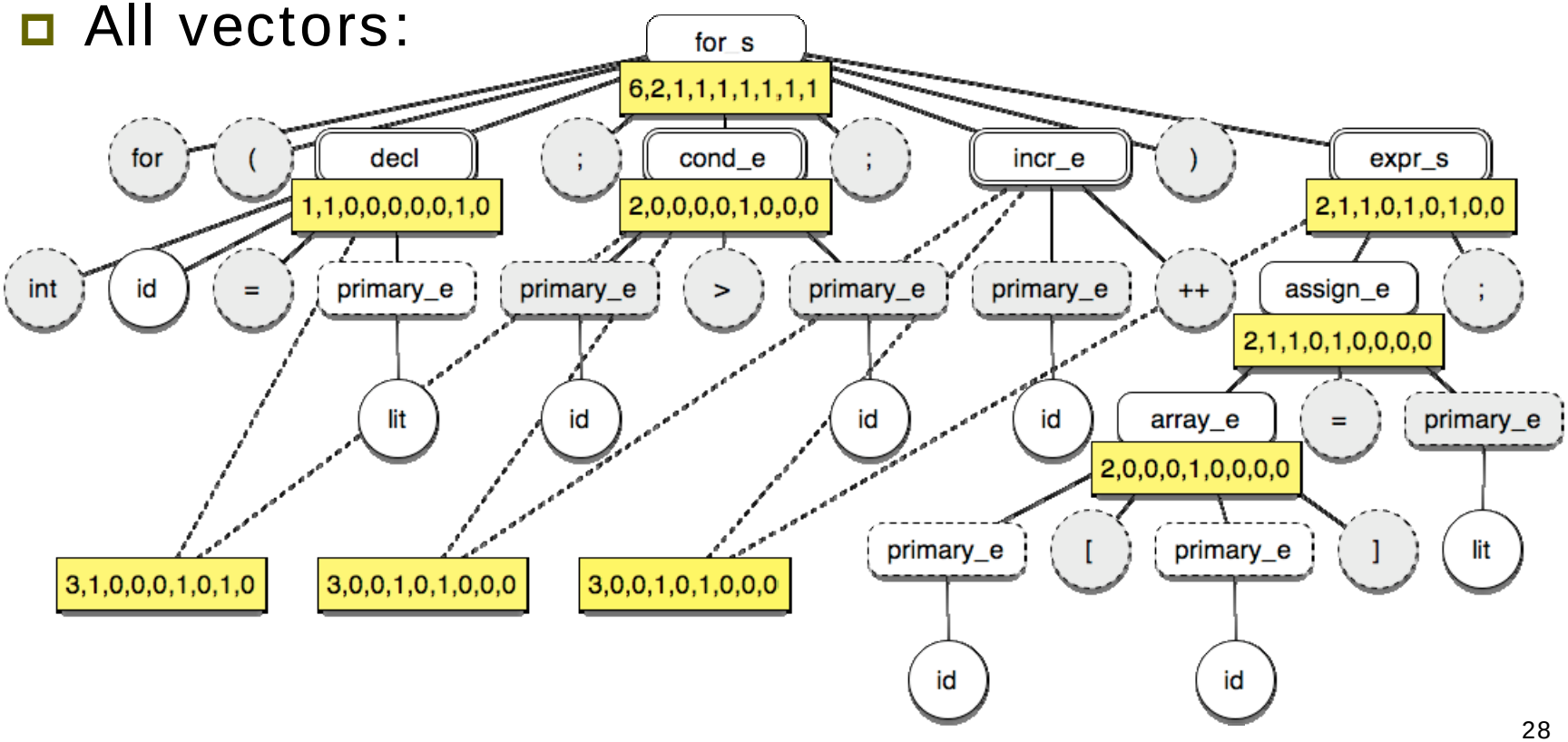


Map Trees to Numerical Vectors (2)

```
for ( int i = 0; i < n; i++ )
   x[i] = 0;
```

<id, lit, assign_e, incr_e, array_e, cond_e, expr_s, decl, for_s>

- All vectors:

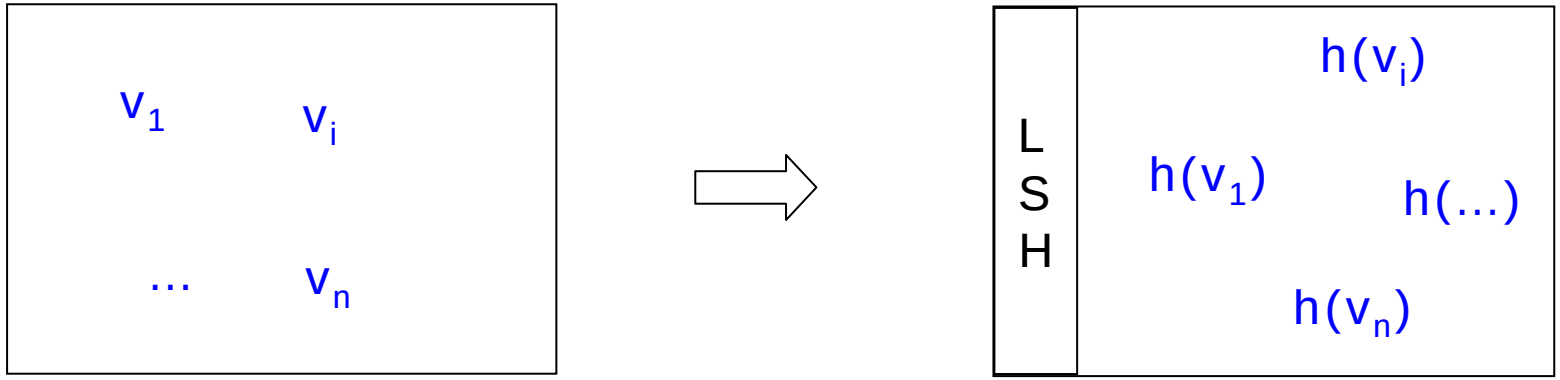


Vector Clustering

- Have millions of generated vectors
- Need to efficiently cluster “close” vectors together
  - Hashing
- Locality-sensitive hashing (LSH)
  - A family of hash functions, s.t., with high probability,
    - Similar vectors hashed to a same hash value
    - Distant vectors hashed to different hash values
  - http://web.mit.edu/andoni/www/LSH/index.html

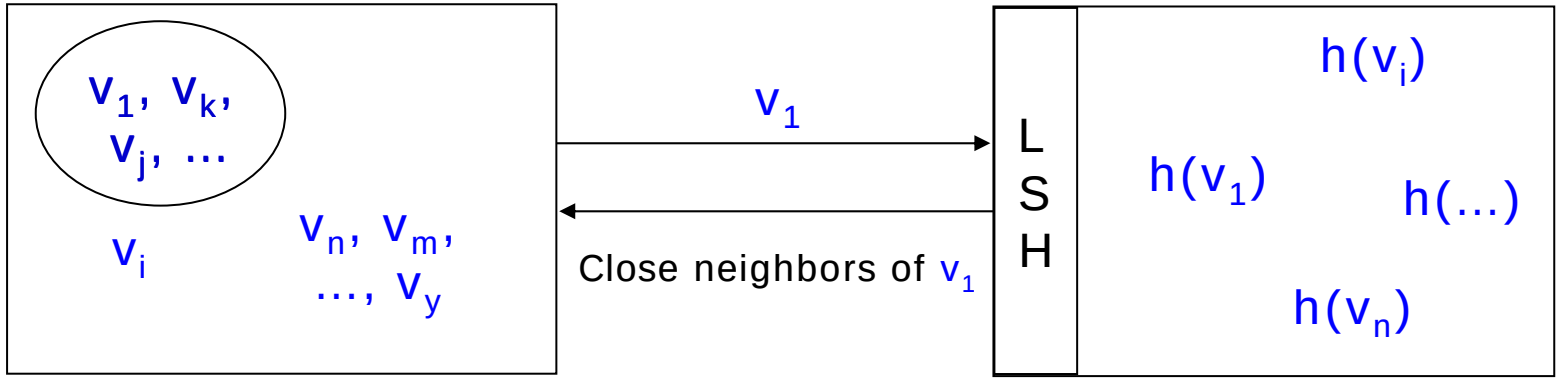
LSH-based Clone Detection (1)

- Rely on LSH to construct hash tables for vectors



LSH-based Clone Detection (2)

- Query LSH for vector clusters



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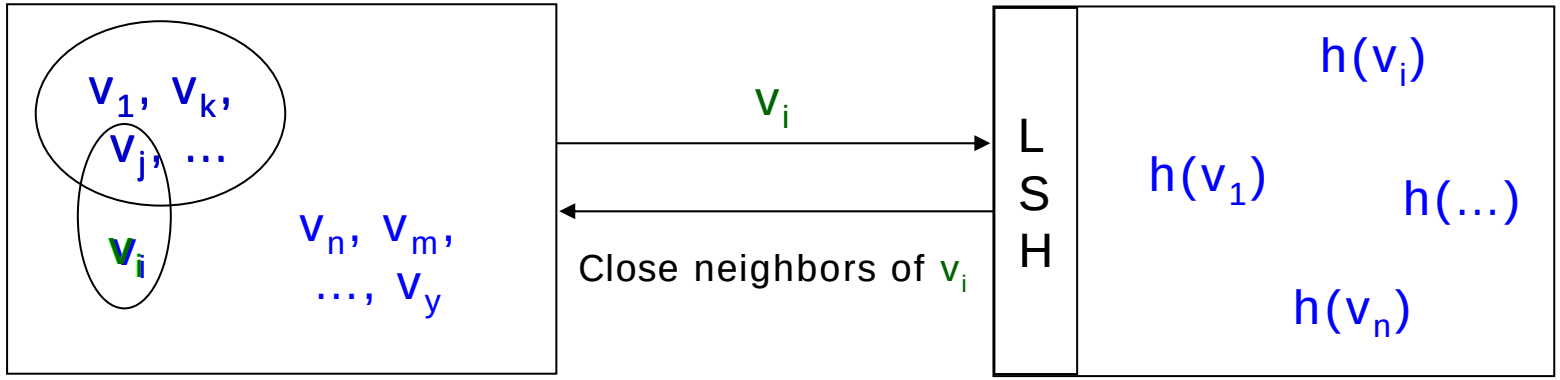

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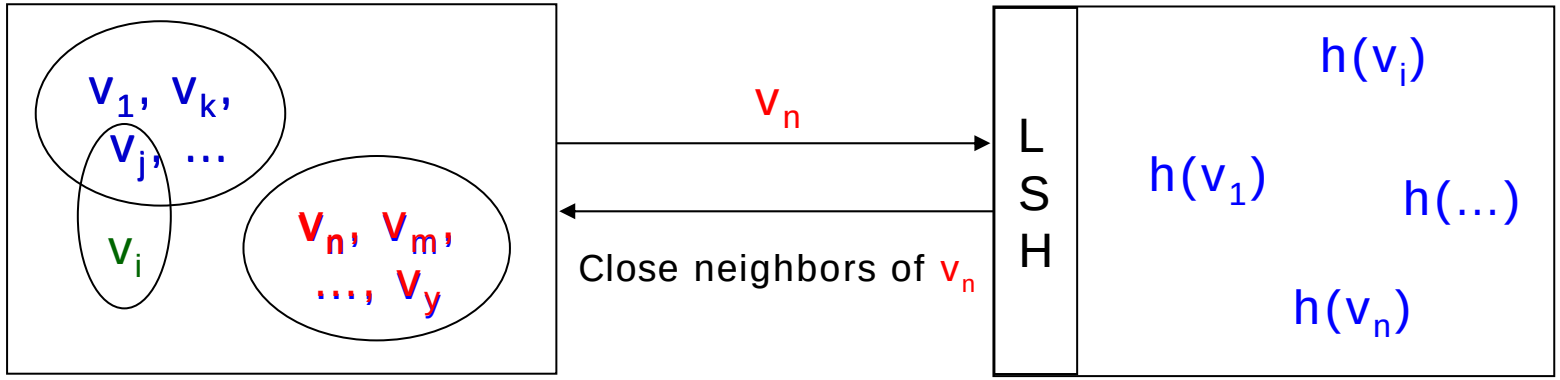

- Post-process to reduce "false" clones
  - Small clones
  - Overlapping/duplicate clones

Test Programs

Application	Language	# files	# lines
Linux kernel 2.6.16	C	7,988	5,287,090
JDK 1.4.2	Java	8,534	2,418,767
GCC 3.3.6	C	7,828	1,246,322
PostgreSQL 8.1.0	C	725	606,015
Derby 10.0.2.1	Java	1,418	523,939
Apache 2.2.0	C	537	269,287

Clone Quality (1)

- Examined 100 clone clusters
  - Randomly selected from JDK 1.4.2
  - Used parameters
    - Similarity: 1.0
    - Minimum clone size in tokens: 50
    - Stride: 4
- Among the 100 clusters
  - 93 are clearly real clones
  - The remaining 7 are difficult to assess
    - But they are structurally similar

Clone Quality (2)

```
if ......
......
else if (option.equalsIgnoreCase(``basic'')) {
        bBasicTraceOn = true;
} else if (option.equalsIgnoreCase(``net'')) {
        bNetTraceOn = true;
} else if (option.equalsIgnoreCase(``security'')) {
        bSecurityTraceOn = true;
} else ......
......
```

```
if ......
......
else if (opt.equals(``-nohelp'')) {
      nohelp = true;
} else if (opt.equals(``-splitindex'')) {
      splitindex = true;
} else if (opt.equals(``-noindex'')) {
      createindex = false;
} else ......
......
```