Typestate-Based Semantic Code Search Over Partial Programs

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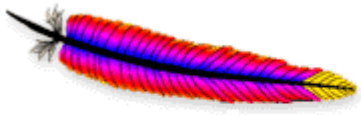
Components Are Everywhere



Apache Commons

Components are Accessed Via APIs

```
class File {
  File(String);
  void open();
  void close();
  byte read();
  void write(byte);
}
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void writeBuff(File f, byte[] buff) {
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  for (byte b : buff) f.write(b);
  f.close();
}
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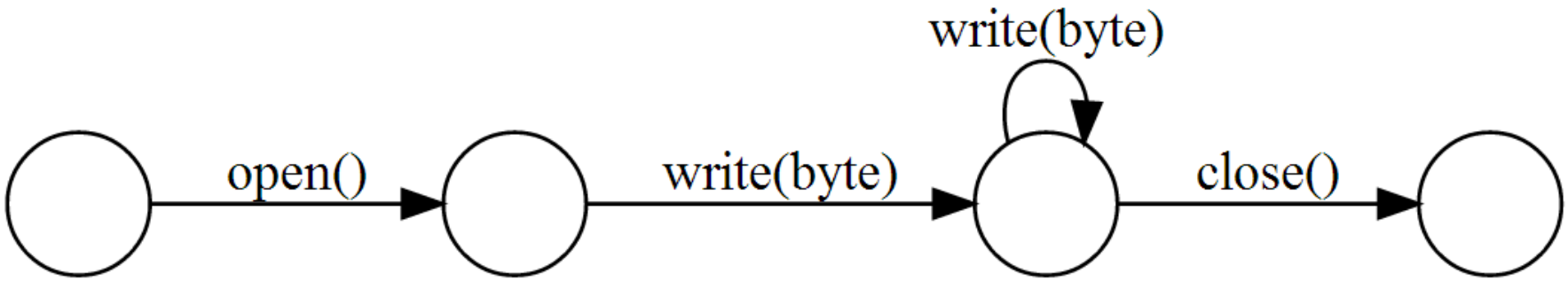
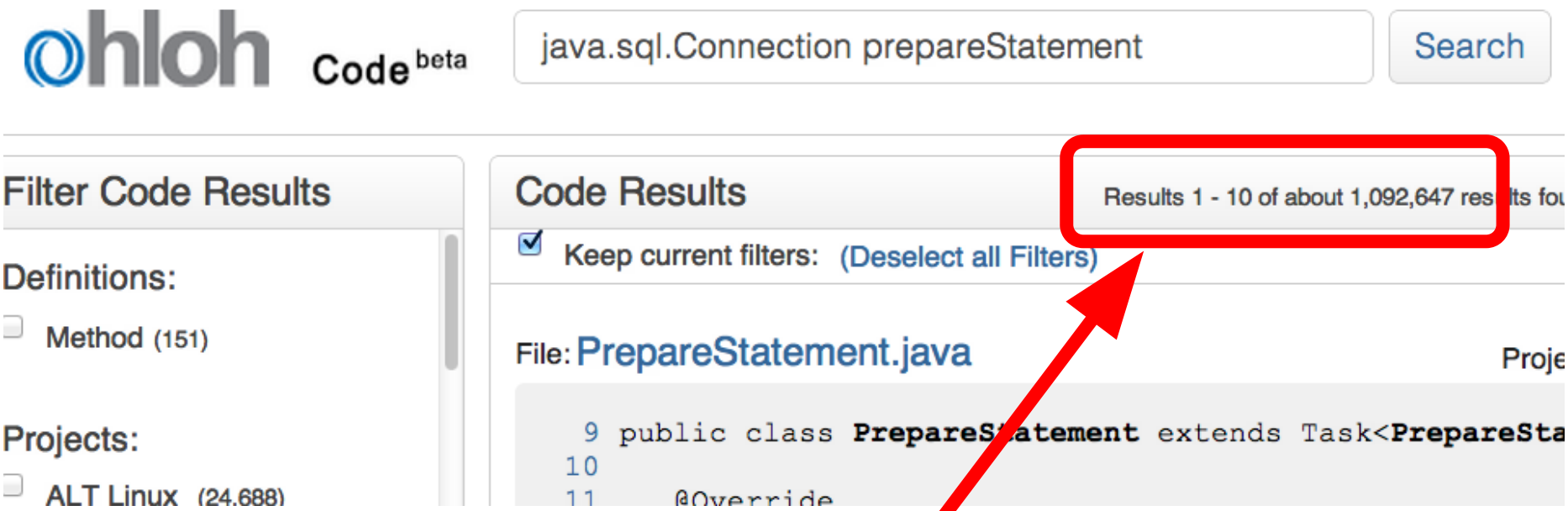


There Are Many Available Examples



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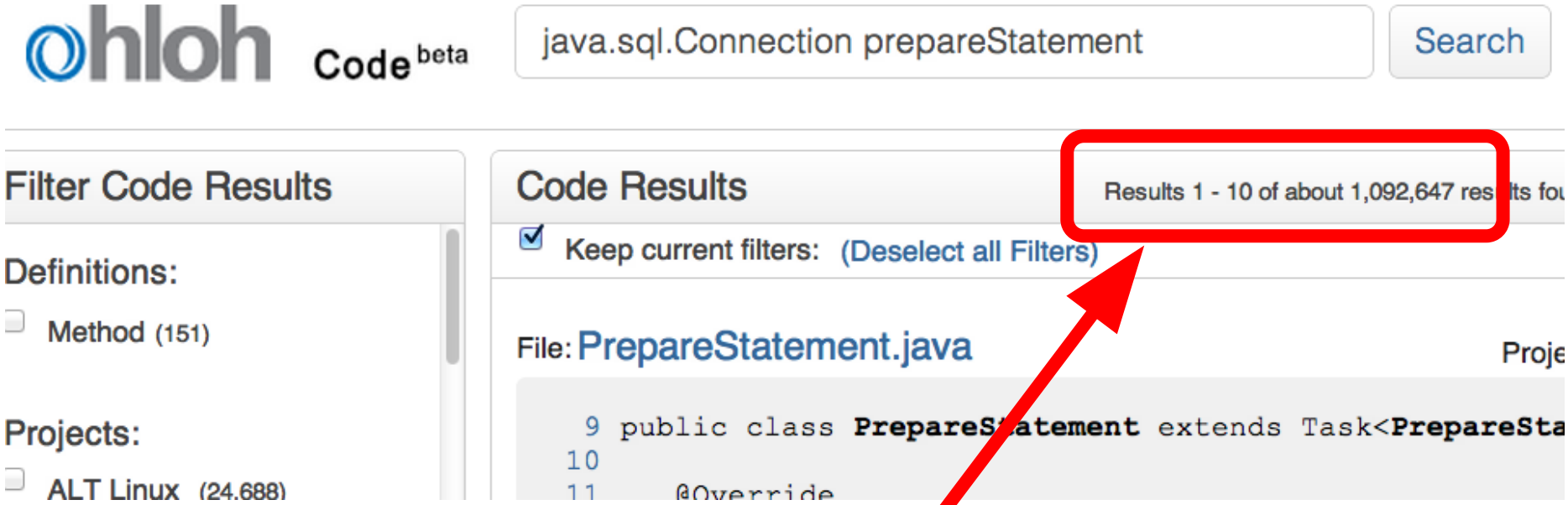

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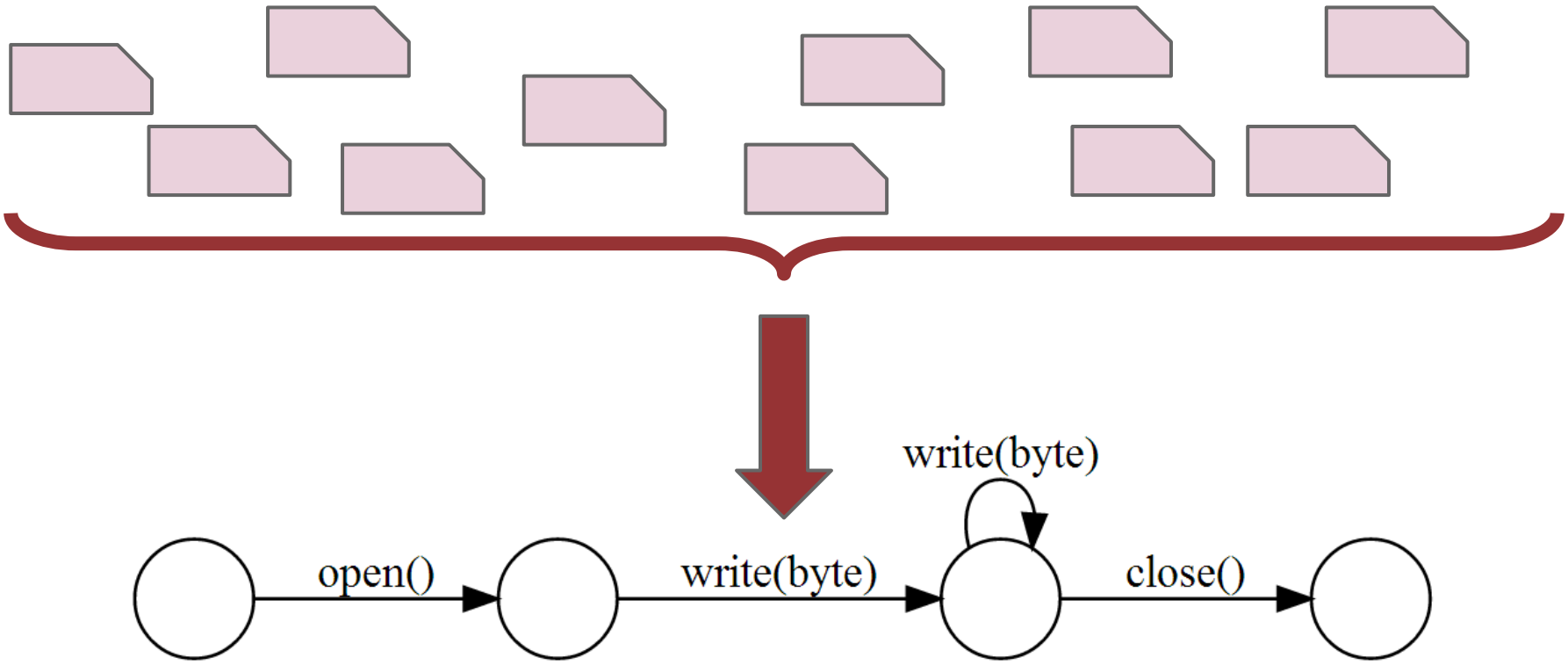
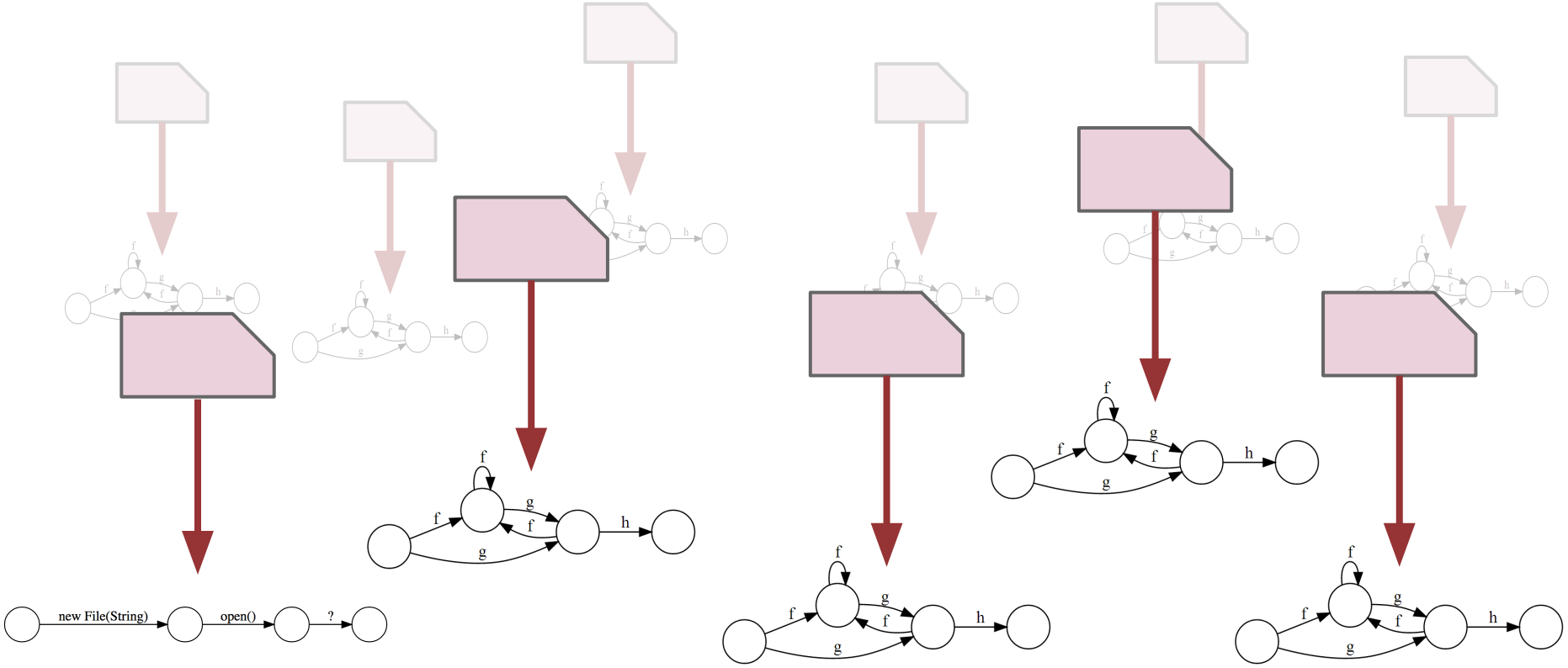
- Partial
- Noisy
- Which one?

Challenge

How do you leverage the huge number of examples for **understanding** how to use the API?



Partial Specification from each Snippet



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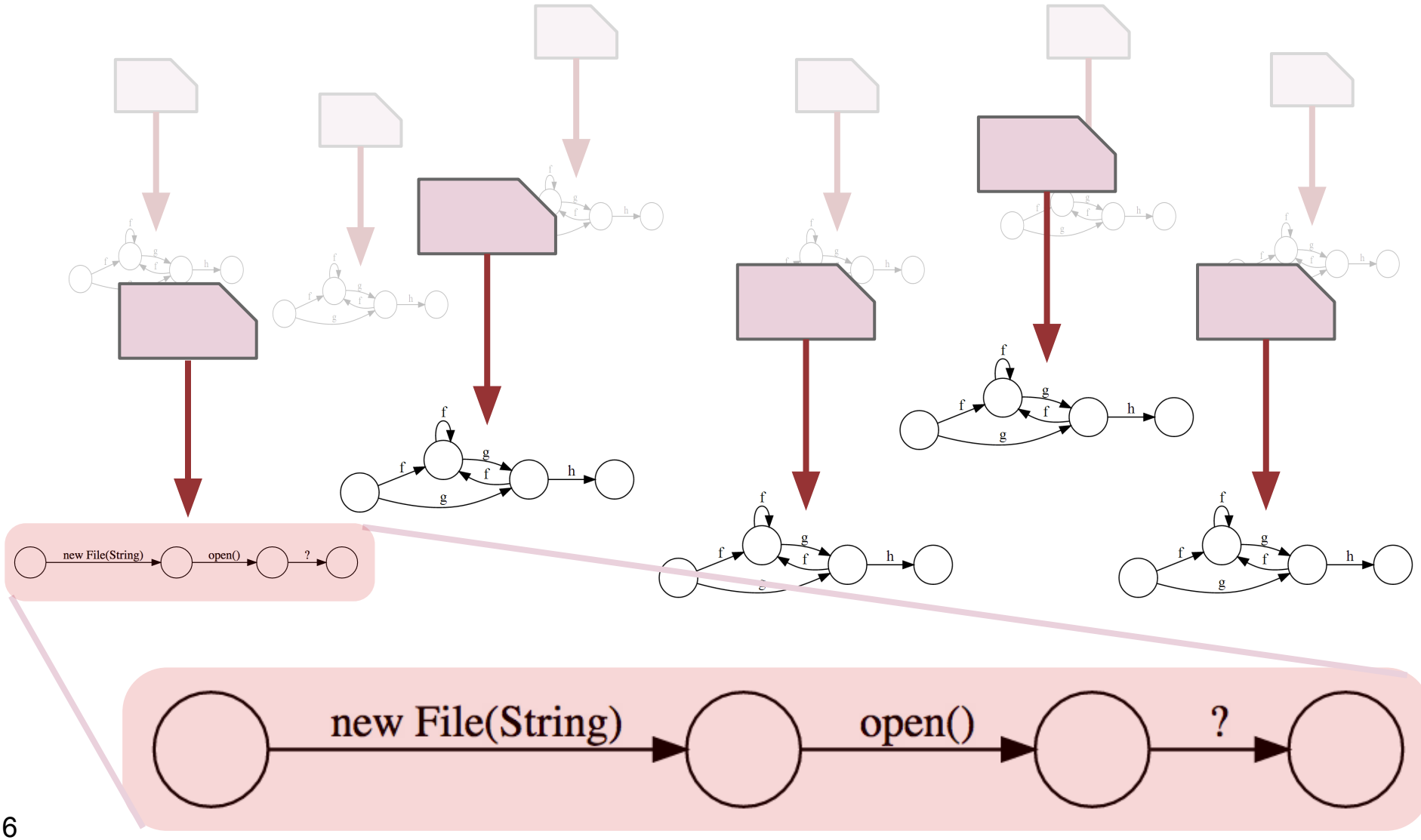
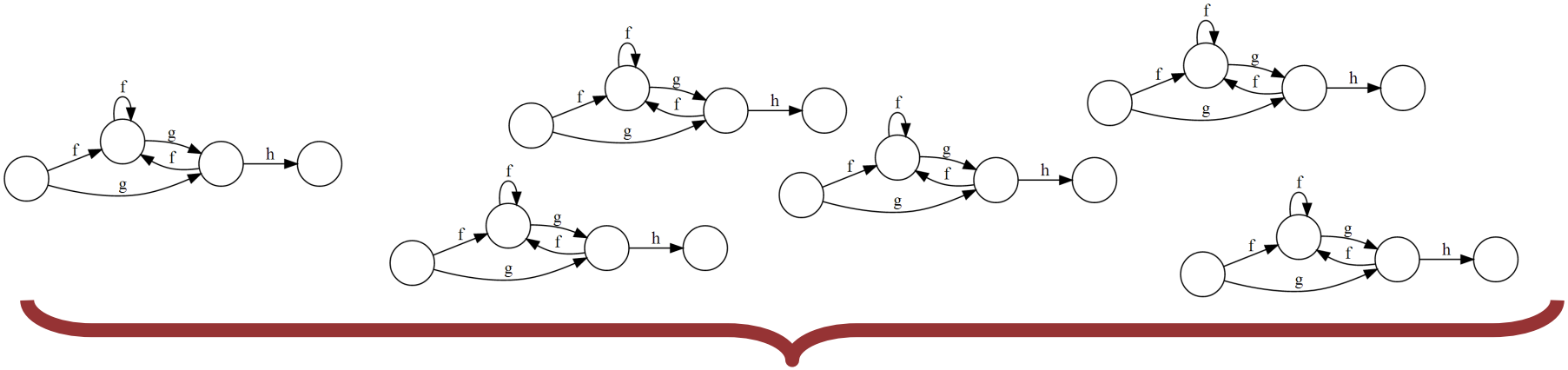


Consolidation Into Larger Specifications



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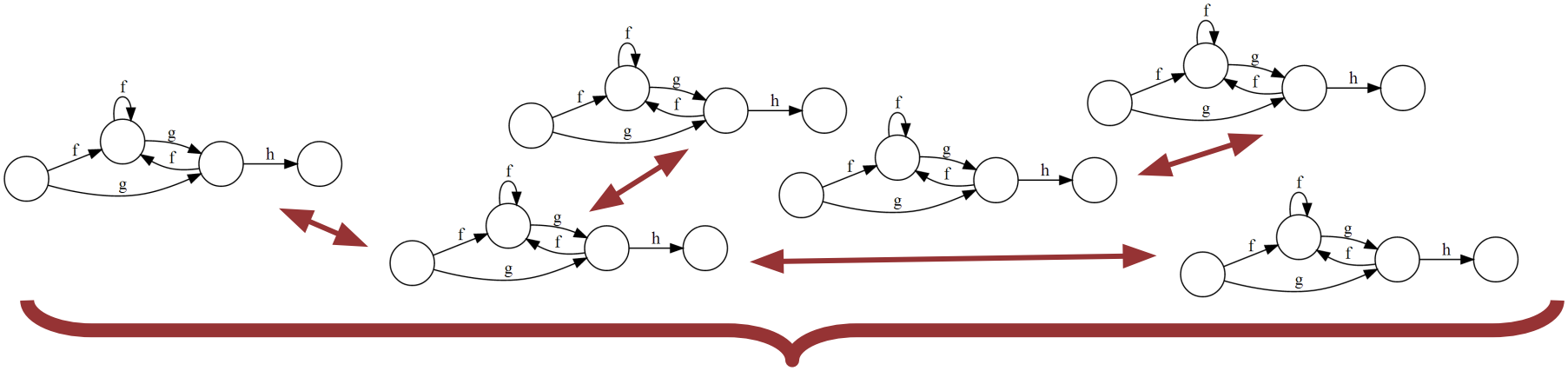

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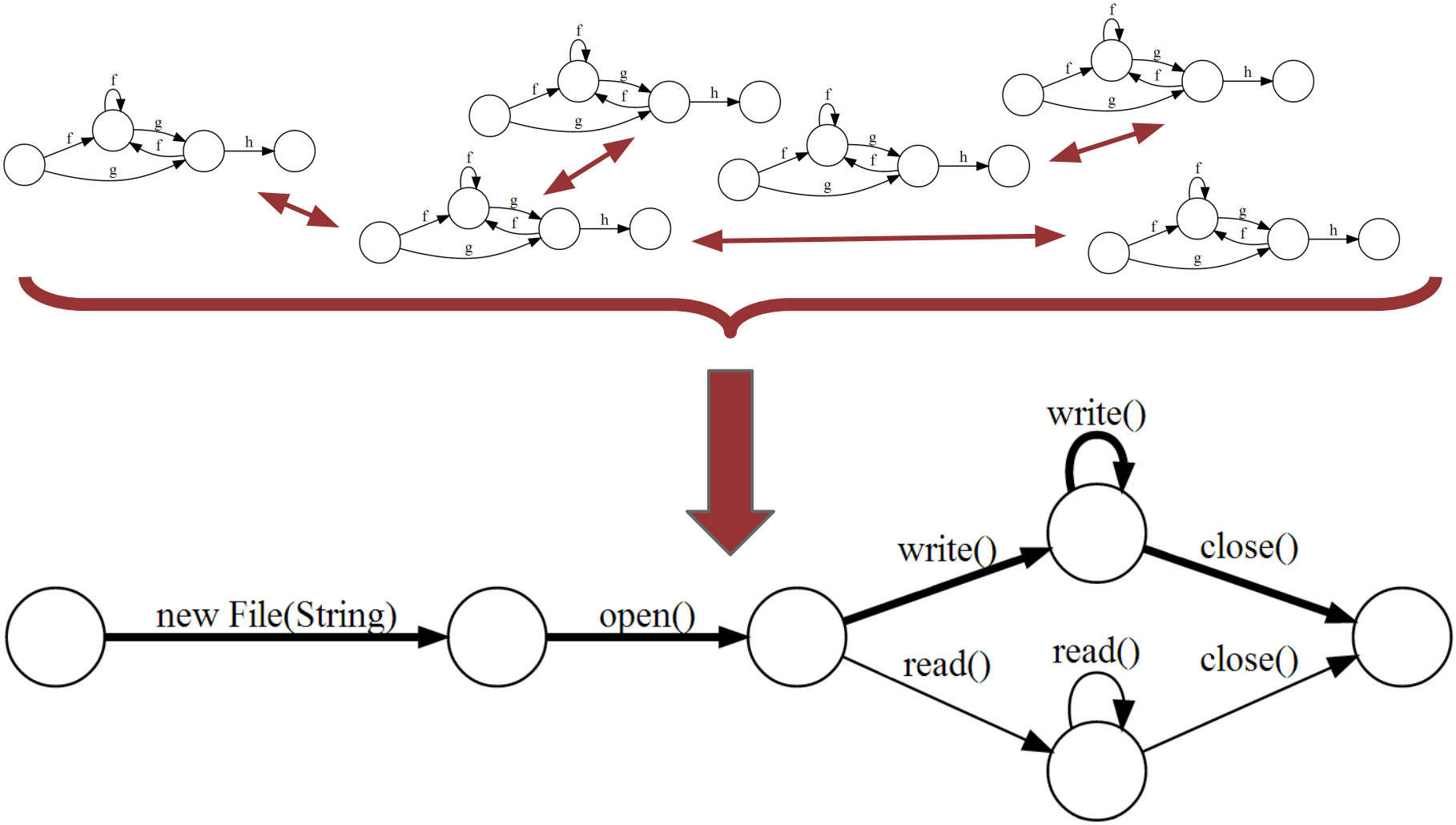
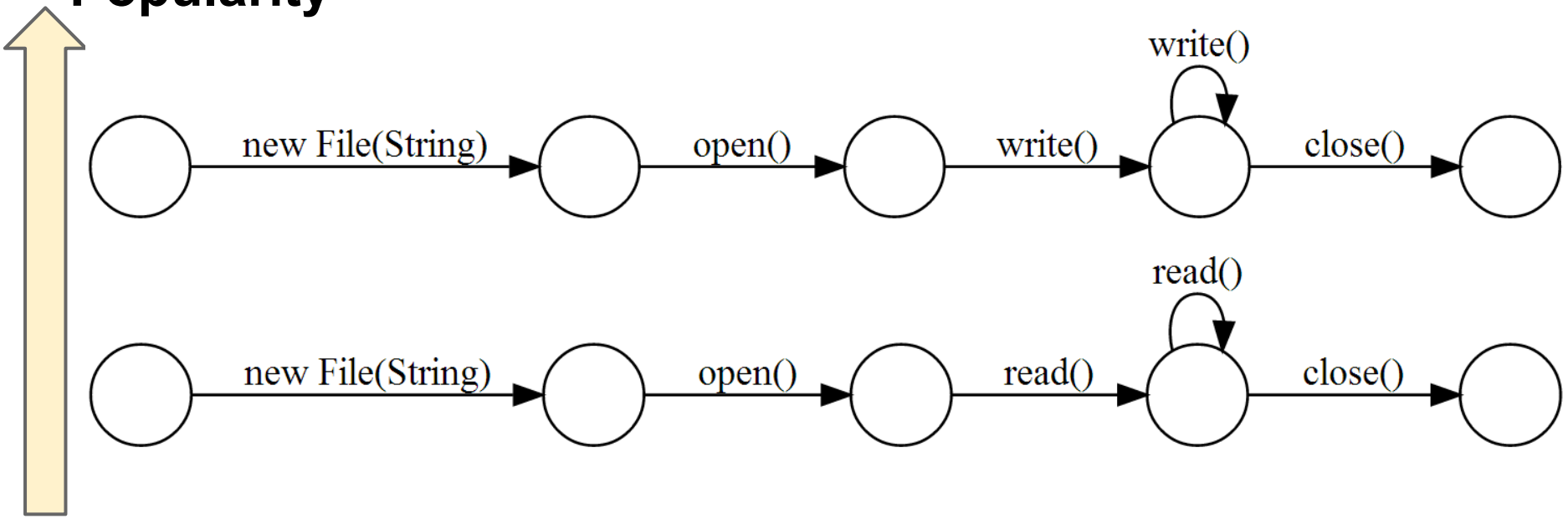


Query Against The Consolidated Specification

```
File f = ?
f.open();
f.?
```

Popularity



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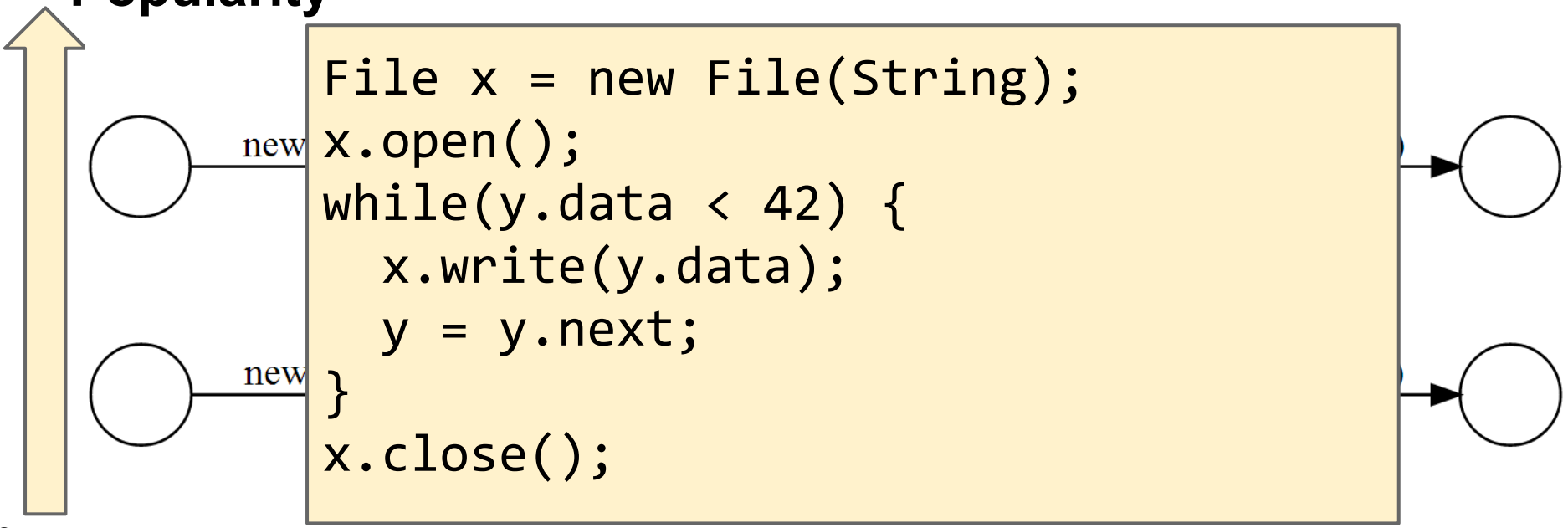
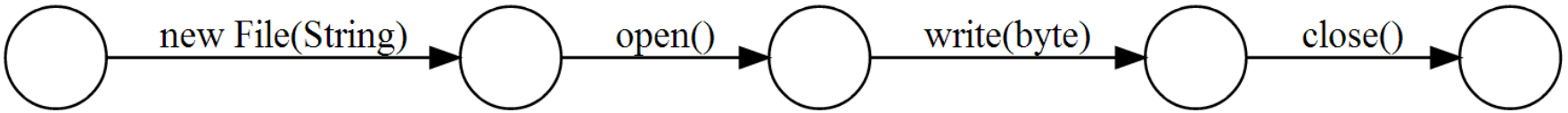


Details

1. Extracting partial specification
   - Data representation
   - Dealing with missing information
2. Consolidating partial specifications
   - Completing missing information
   - Tracking popularity
3. Query matching
   - Matching queries to specifications
   - Ranking by popularity
   - Getting back code examples

Client-Side Static Analysis

```
1    File f = new File(filename);
2    f.open();
3    f.write(...);
4    f.close();
```



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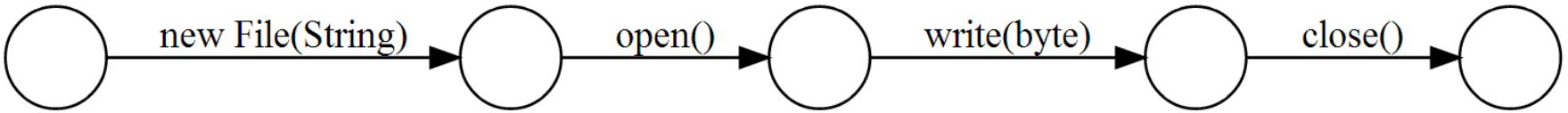

- Handles branches and loops
- Interprocedural
- Alias-aware with points-to information

Abstraction

```
while(...) {
  File f = new File(filename);
  f.open();
  while(...) f.write(...);
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Unbounded sequence of events

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Unbounded number of objects

Unbounded sequence of events

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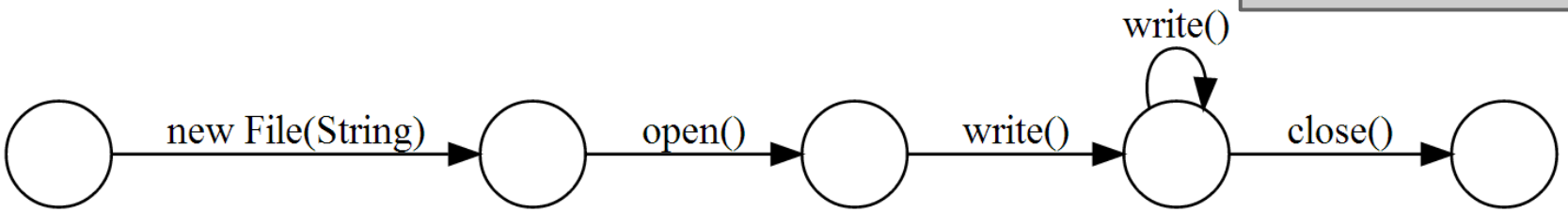

- Represent unbounded sequence of events using finite-state automaton
- Represent unbounded number of concrete objects using abstract objects

Dealing With Multiple Related Objects

```
class FileManager {
  FileManager();
  File getFile(String);
}

class File {
  void open();
  void close();
  byte read();
  void write(byte);
}
```

```
File getOpenFile(String filename) {
  FileManager fm =
    new FileManager();
  File f = fm.getFile(filename);
  f.open();
  return f;
}
```

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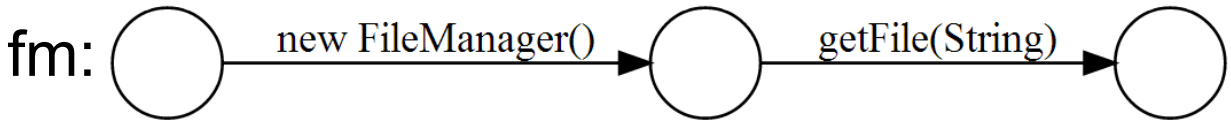

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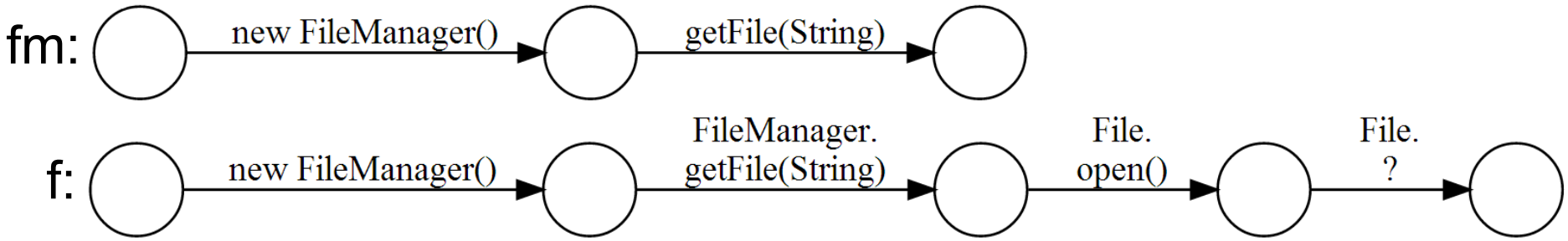

Dealing With Missing Information

```
void process(File f) {
  f.open();
  doSomething(f);
  f.close();
}
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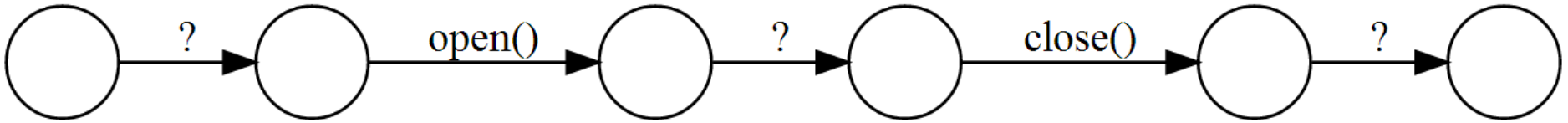
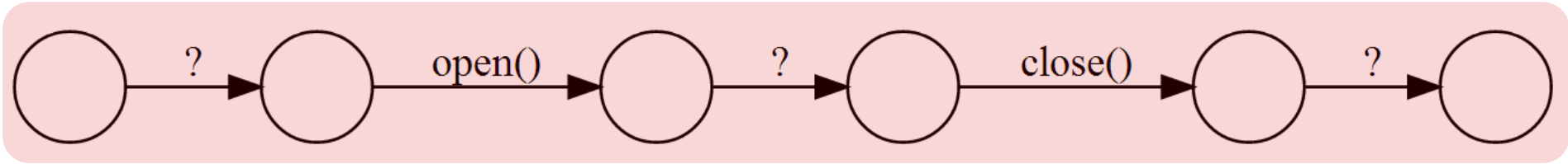


Unknown Elimination



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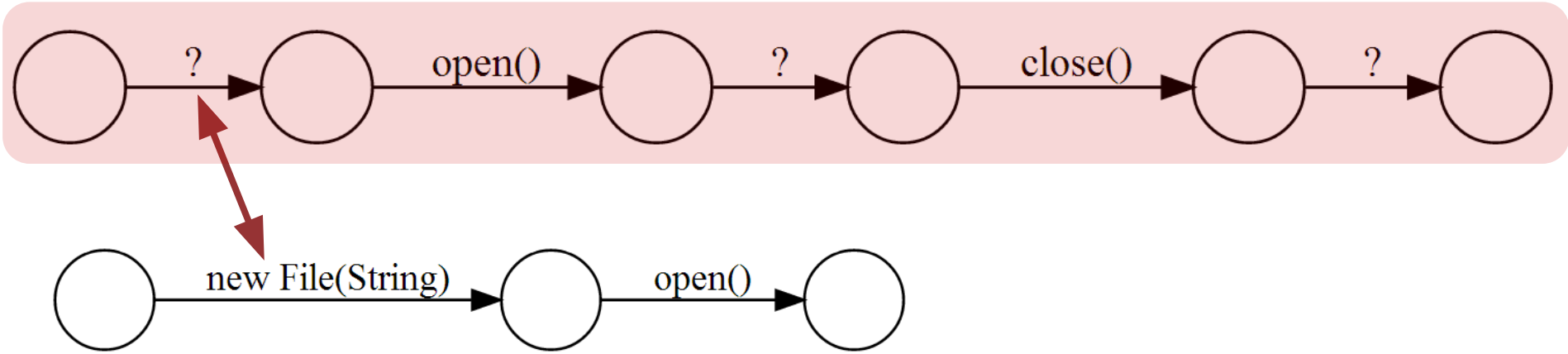

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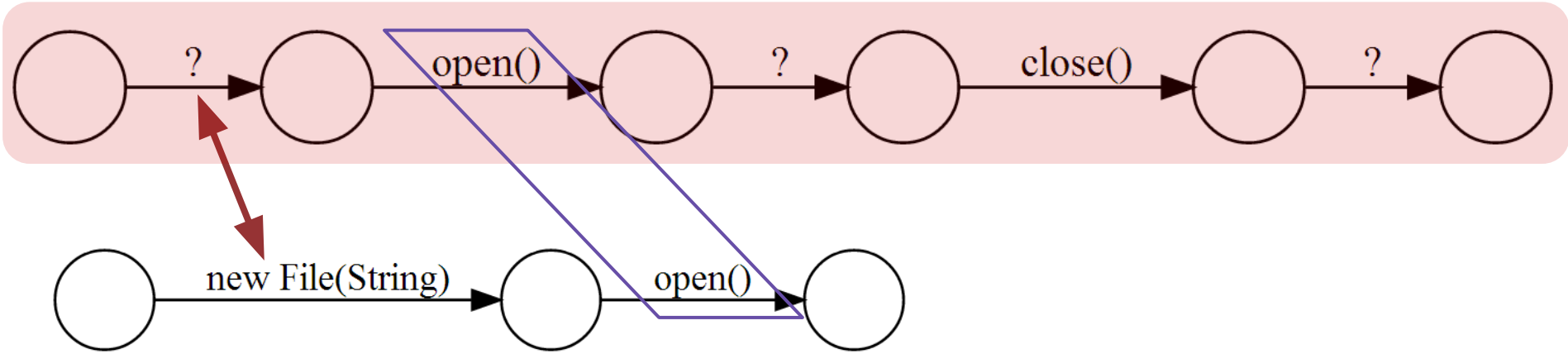

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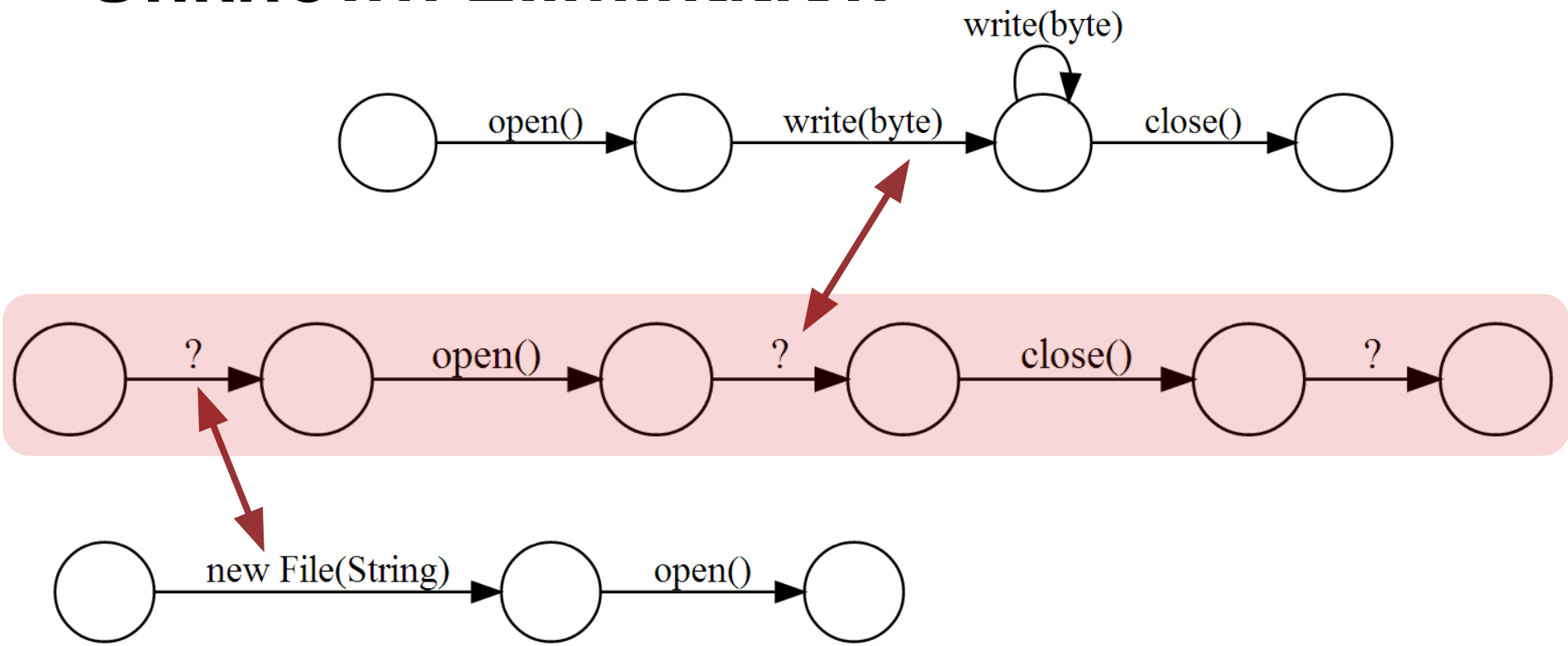

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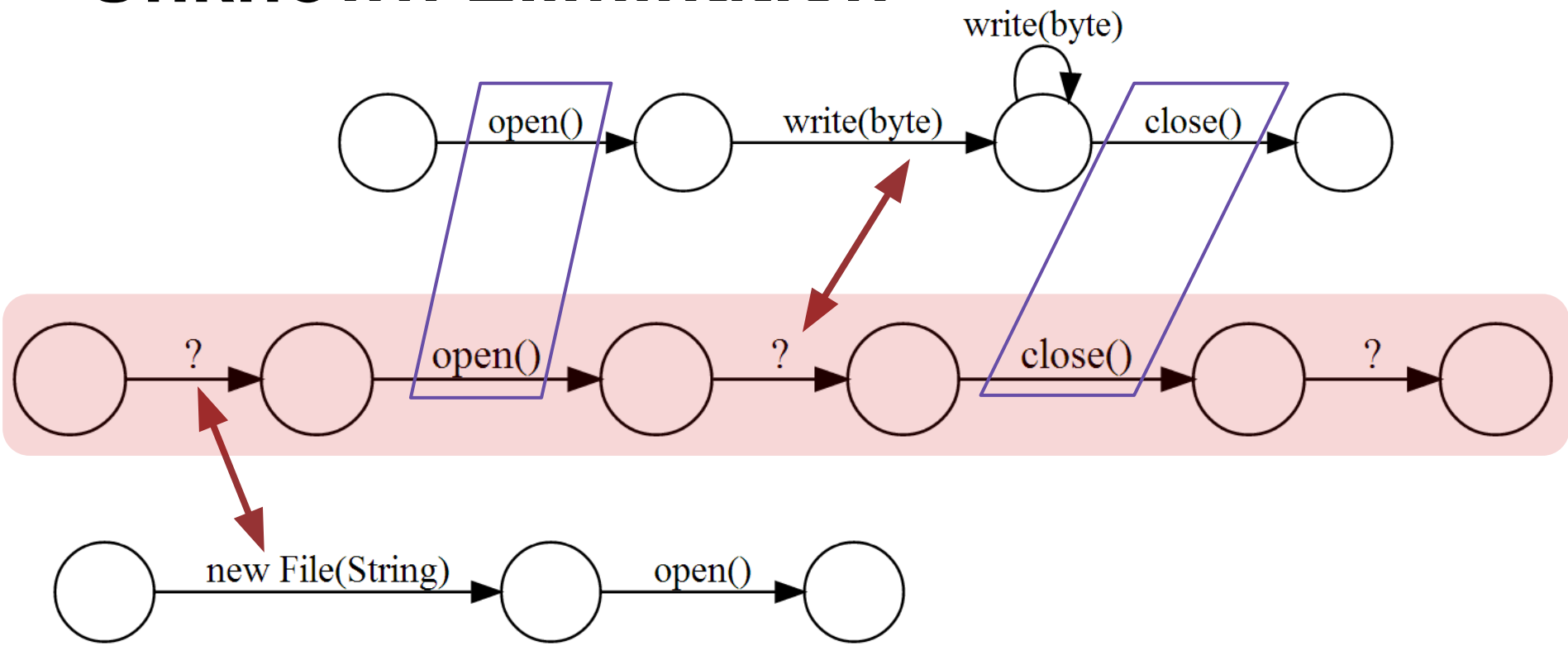

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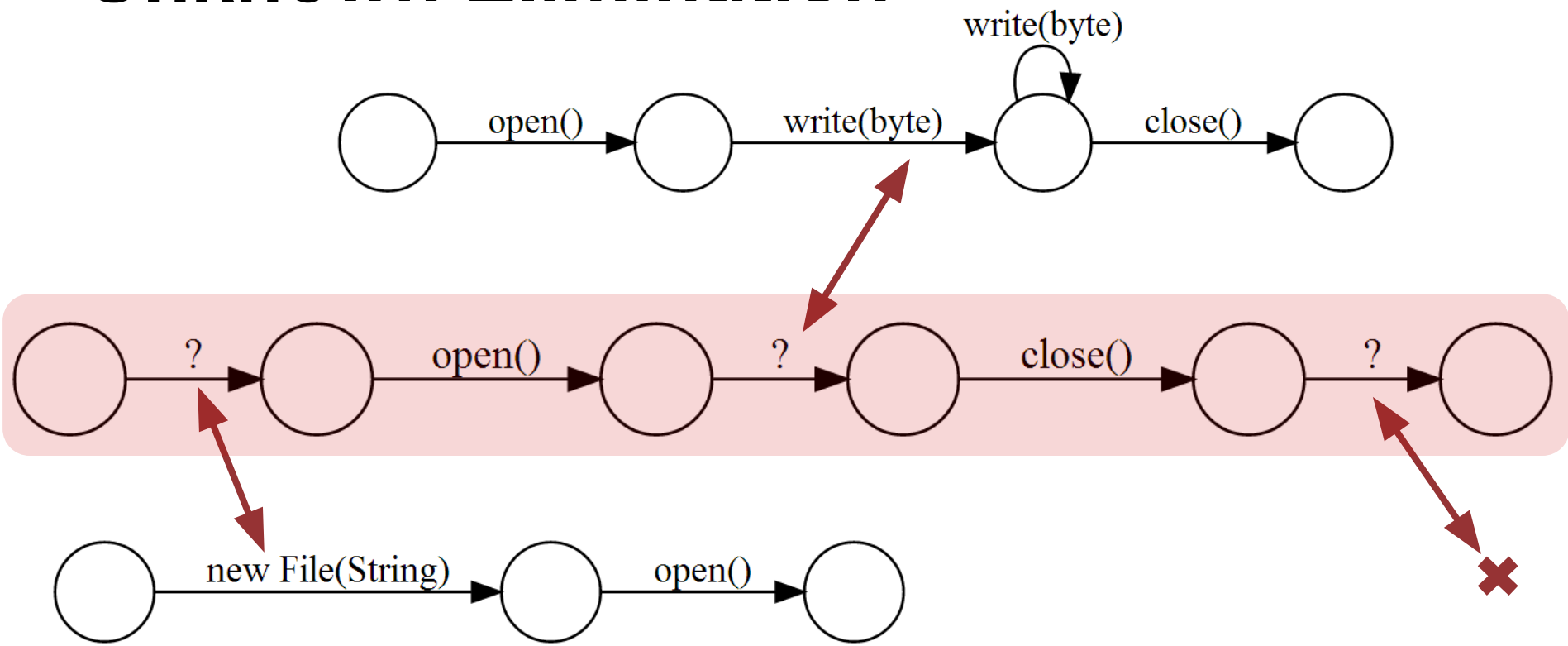

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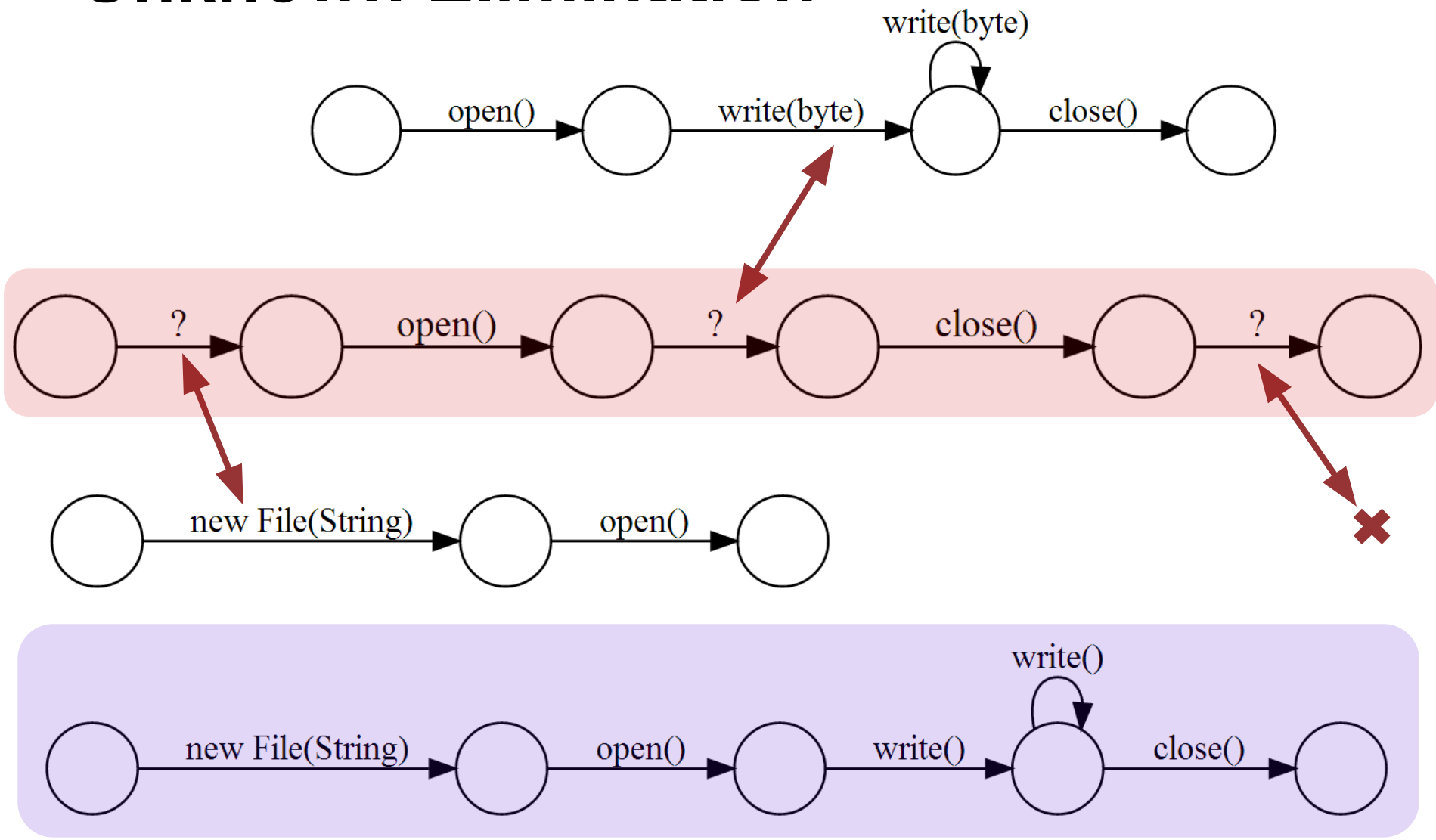
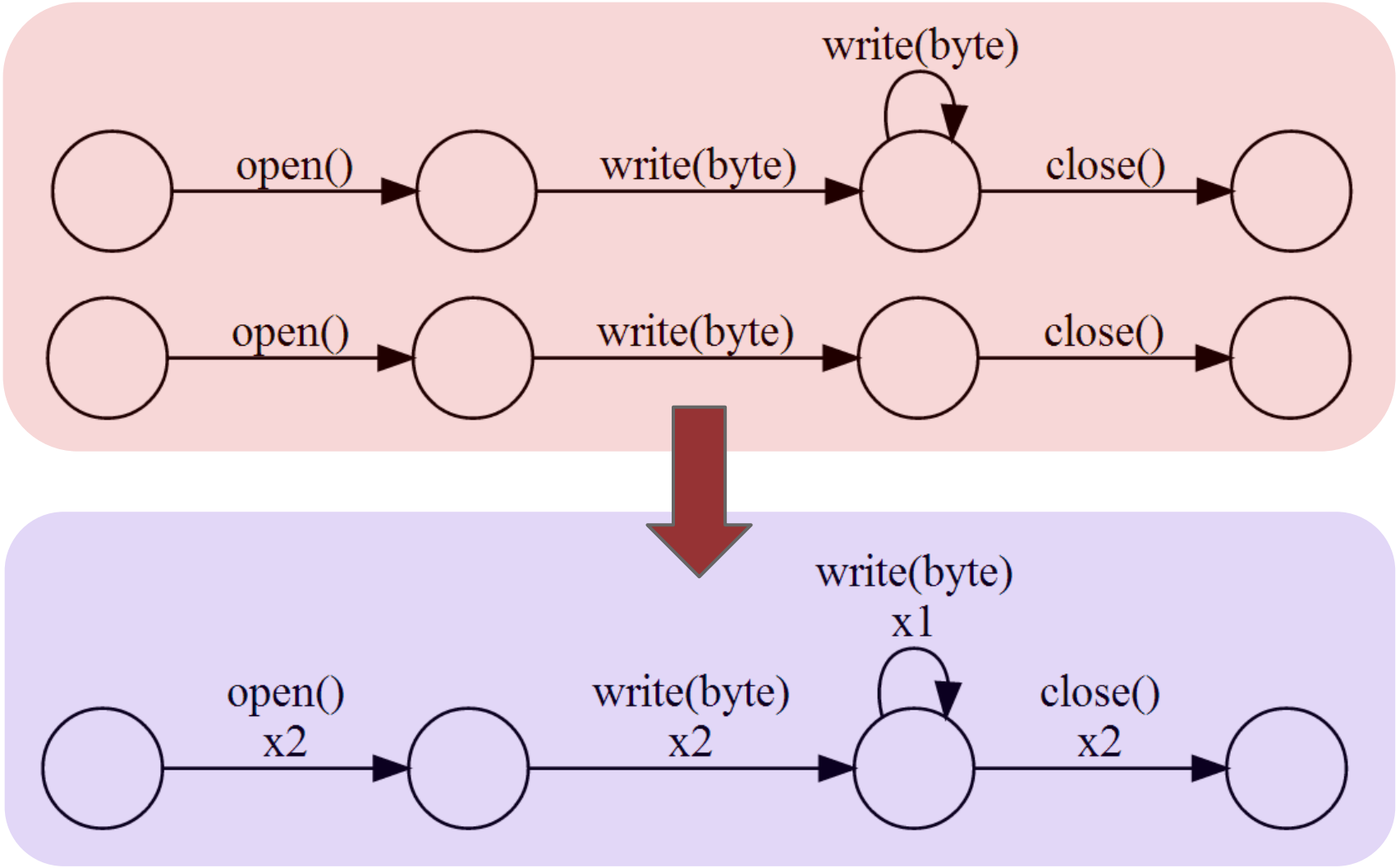


Grouping and Merging



Matching Queries With Examples

Query

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```

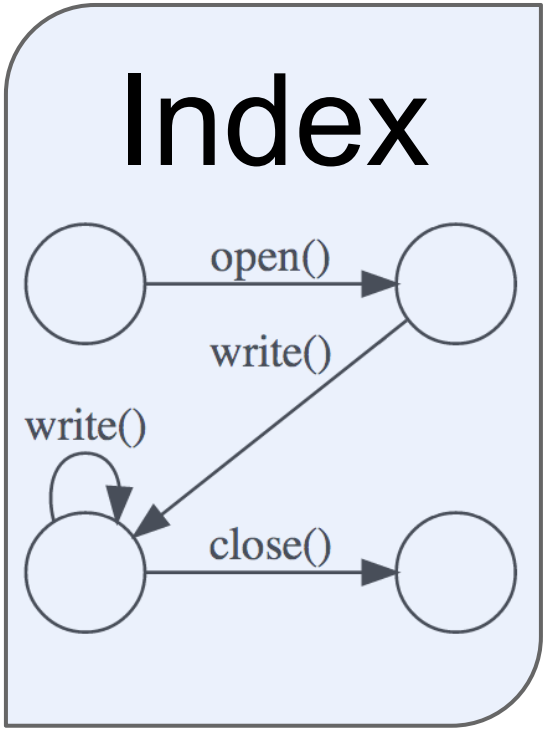

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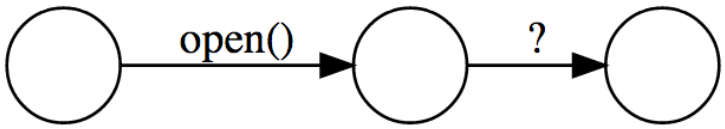

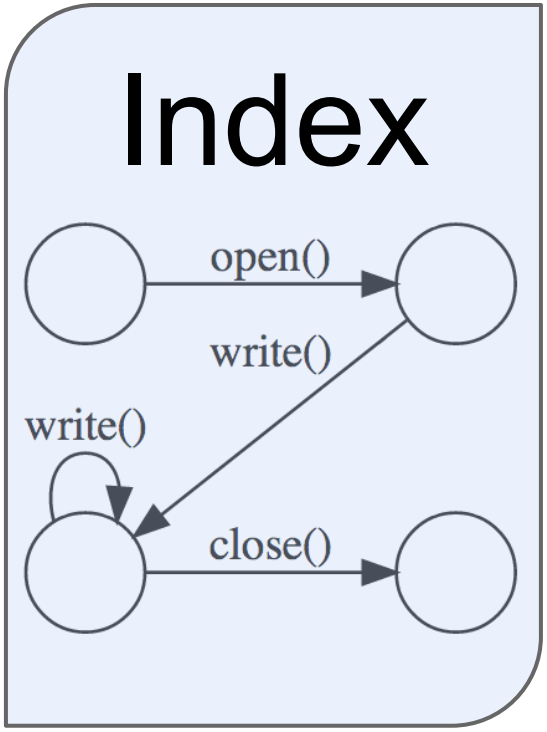

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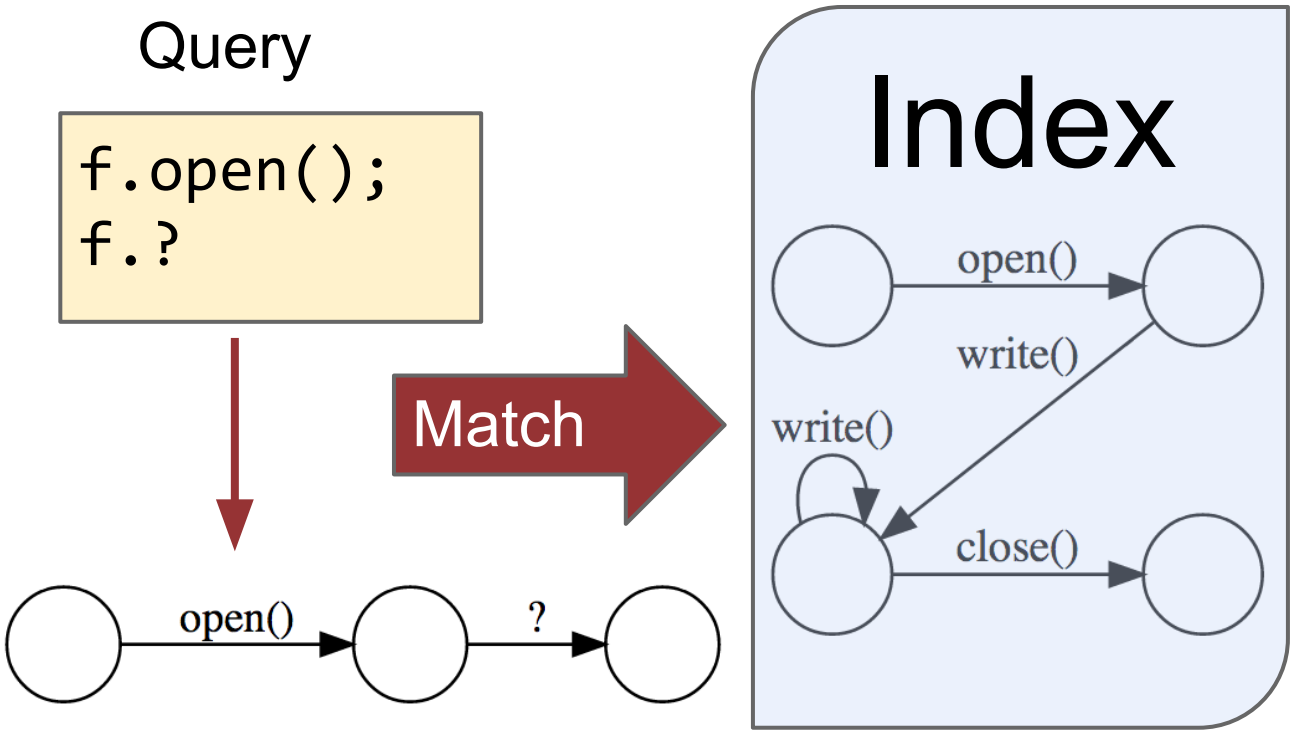
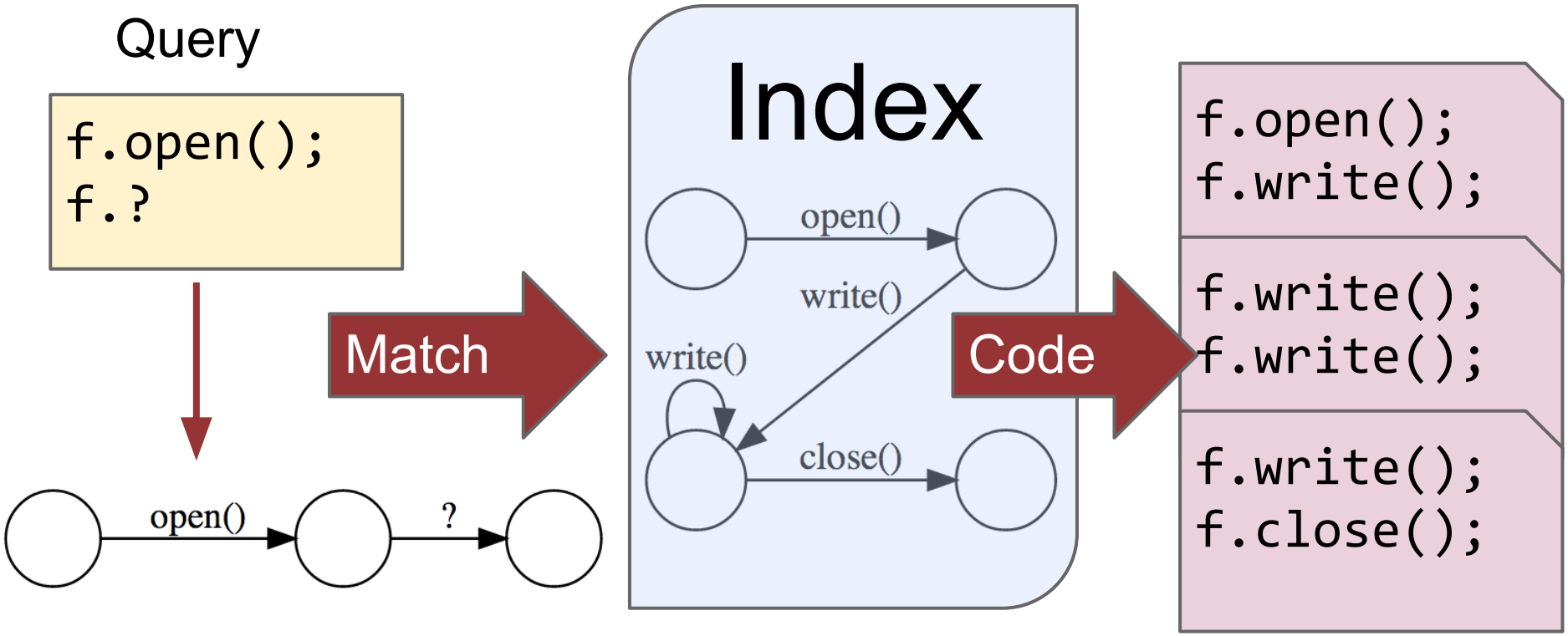


Match: A relaxed form of automata inclusion algorithm, taking unknown edges into account

Matching Queries With Examples



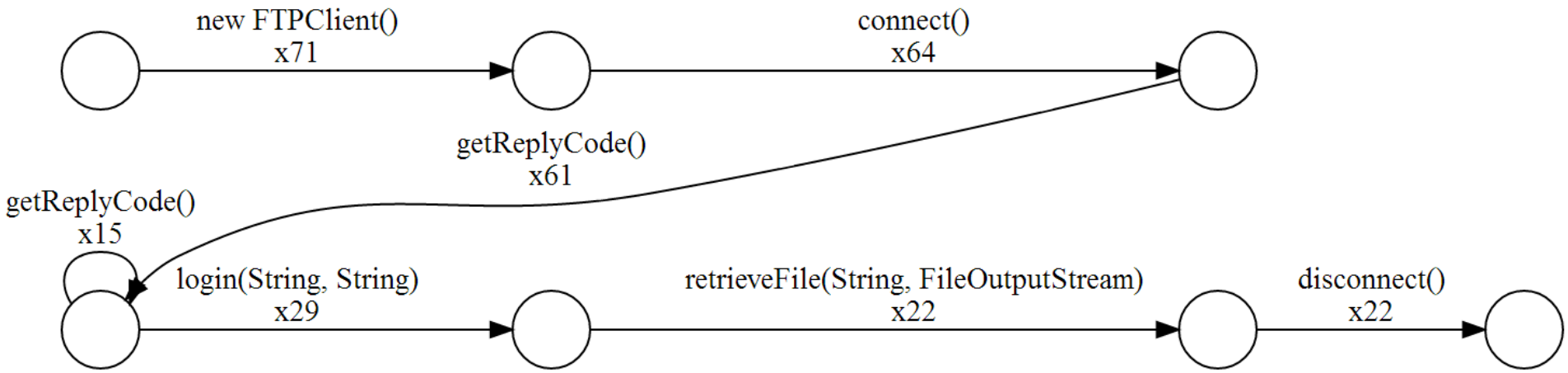
Match: A relaxed form of automata inclusion algorithm, taking unknown edges into account

Evaluation

- Indexed 8 popular APIs, with thousands of examples each
  - Indexing takes hours
  - Querying takes seconds (can be optimized further)
- Consolidation is effective
  - Found long sequences that cannot be found using individual examples
- Ranking is effective
  - Examples covering full tutorial scenario found in the top matches
- Creation context is important in practice
  - Many APIs require sequences over multiple objects

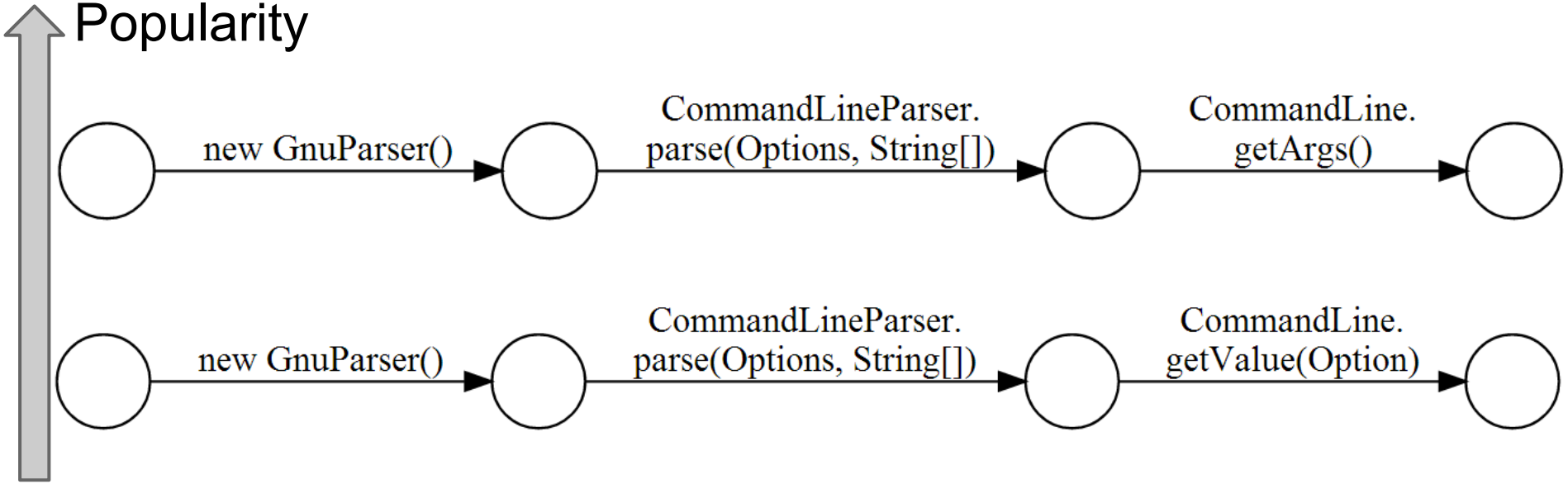
Example Result: Complete Sequence

```
FTPClient c = ?;
c.login("username", "password");
c.?;
c.retrieveFile("file path", out);
```



Example Result: Query Over Multiple Types

```
GnuParser p = new GnuParser();
p.?;
String s = p.?;
```



Conclusions

- Leverages the **vast** number of available examples
- Builds **consolidated and distilled** API usage specifications from the many partial examples
- Automatically presents the most **popular** sequences that still **match** the query

It Works and is Open-Source!

This work is implemented in an open-source tool called **PRIME**, available on sourceforge, at:

priming.sf.net

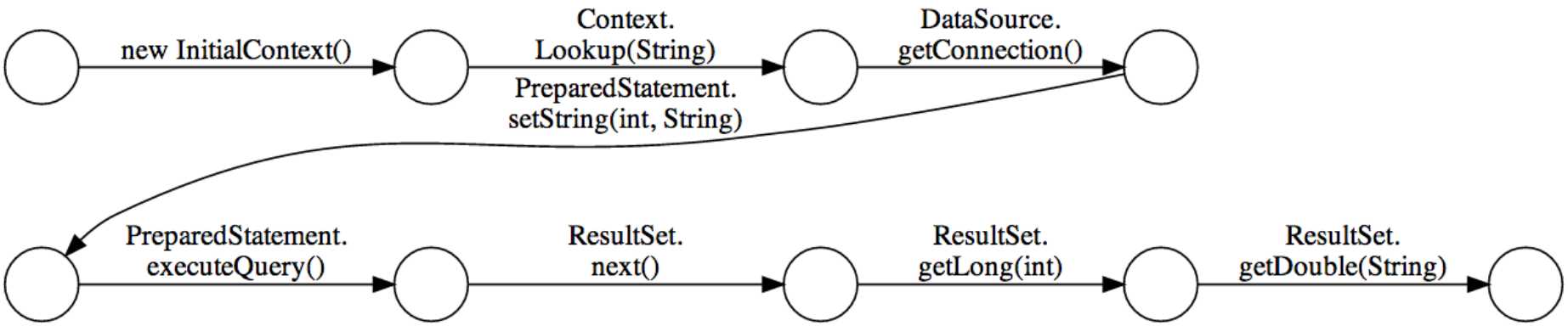
Backup

Closest Related Work

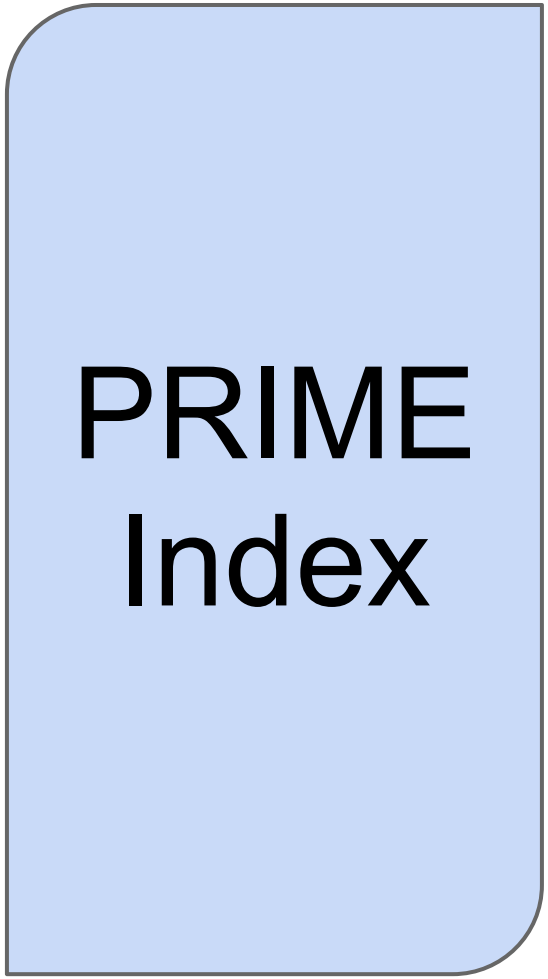
- Zhong's MAPO
  - Only simple sequences (no loops)
  - Can't handle partial code (needs compilation)
  - More and better results for same API
  - Noisy since it doesn't track per-object
- Thummalapenta and Xie's PARSEWeb
  - Can handle partial
  - Only object types
  - AST-based
  - Only how to get one type from another.
- Mandelin's Jungloids
  - Only type safety, no typestate
  - We cover (some of) their examples

Example Result: Long Query

```
InitialContext ic =
new InitialContext();
ic.?;
PreparedStatement ps = ic.?;
ResultSet rs = ps.executeQuery();
rs.?;
double d = rs.getDouble("column");
```



Additional Applications



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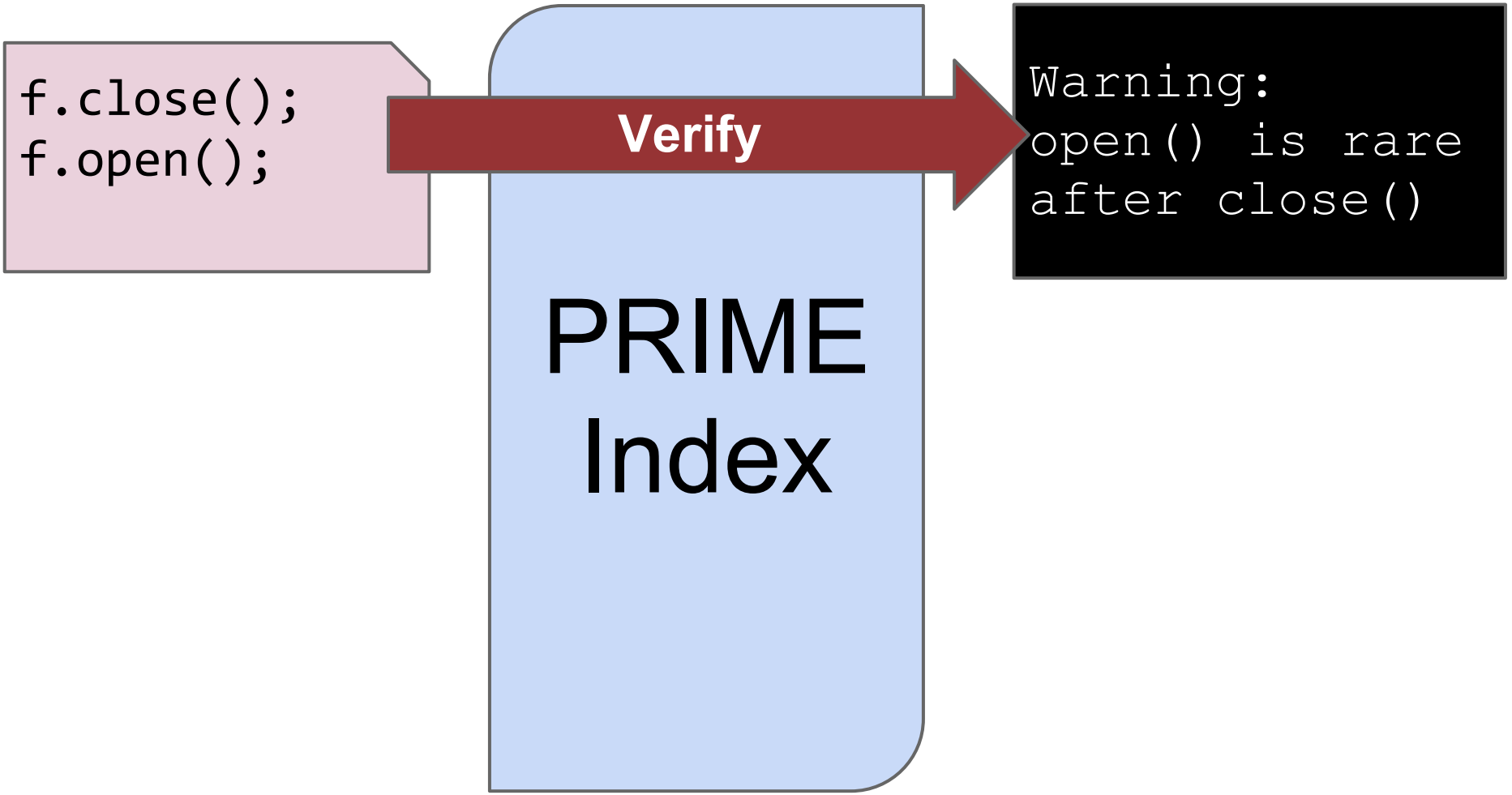

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