The Program Understanding Problem: Analysis and A Heuristic Approach

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March, 1996

Large Legacy Code is Hard to Maintain

→ *Large* legacy source code presents many challenges for software maintainers :

- Code becomes increasingly difficult to extend or debug
  - ⋆ Dispersed, local, or non-existent knowledge of code function,libraries
  - ⋆ Contains old embedded unused code
  - ⋆ Redundant code and functionality
- Inconsistent, outdated and non-existent documentation
- ... many other problems ...

A Legacy Code Fragment to Consider

```
main()
{
   // documentation describing an older version of code
   char* A, B, C;
  A = "s" + "t" + "r" + "i" + "n" + "g" + "1";
  B = "string2"
  // description of non-existing variables, omitting current
  sz = 7;
  for (int j = sz;  j>0; j--){
      C[sz-j] = B[sz-j]; }
  C[sz] = "3";
  for (int i=0; B[i]; i++){
       print(B[i]); }
  // comment referring to non-existent code
  for (int j=0; j++){
       printf("%s",C[i]); }
  // reference to outdated documentation, old library
  for (int k=0; A[k]; k++){
      outchar(A[k]); }
  }      // end of main
```

Legacy Code Maintenance

→ Maintainers attempt to alleviate these problems by :

- Rewriting all or some systems if practical
- Consolidating code functionality where possible
- Simplifying code via shared or commerical libraries

→ In order to manipulate legacy source, maintainers must:

- Possess knowledge about *domain*, *general* program plans
- *Understand* a given legacy source in this context

→ **But what does it mean to** ***Understand*** **legacy source ?**

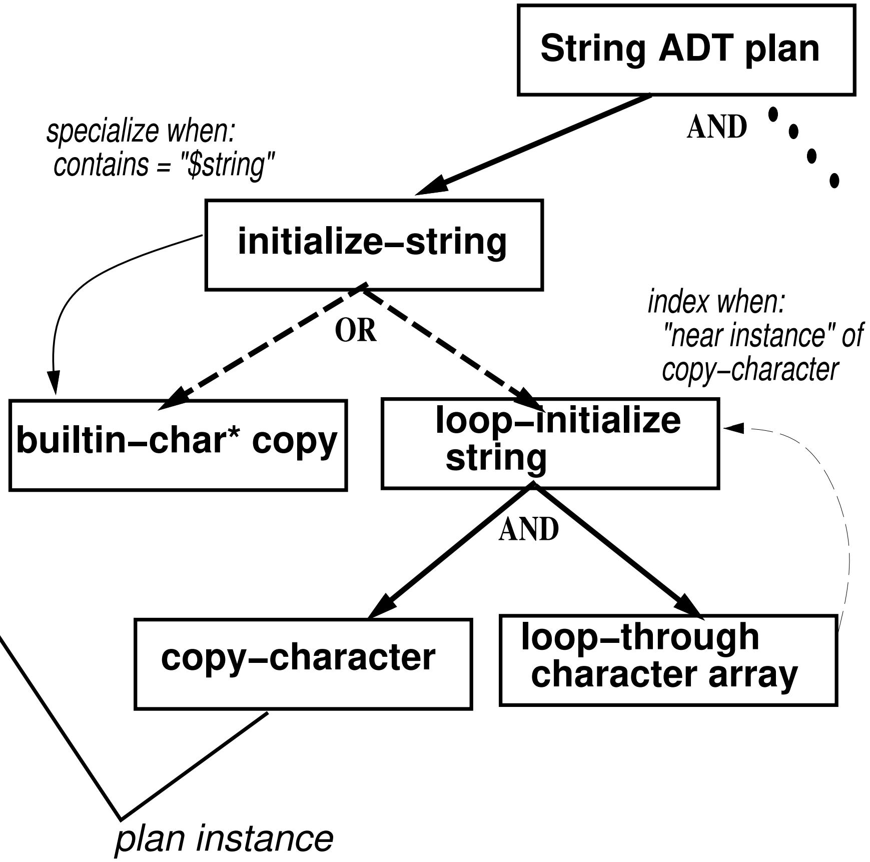
→ **How hard is it to** ***Understand*** **legacy source ?**

Understanding Legacy Code : Knowledge Mapping

Legacy Source Code

```
main()
{
  char* A, B, C;
  ...

  A = "s" + "t" + "r" + "i" + "n" + "g" +  "1";
   ...

  B = "string 2";
  ...
  sz = 7;
  for (int j = sz; j > 0; j––) {
      ....
      C[sz – j] = B[sz – j];
      ... }
  ...
  C[sz] = 3;
  ...

  for (int i=0; B[i]; i++)
       ...
     print(B[i])
       ....
  ...

  for (int j=0; C[j];j++) {
       ....
       printf("%s",C[i]);
       ... }
  ...
  for (int k=0;A[k]; k++) {
       ...
       outchar(A[k]);
       ... }
  ...}
```

Program Plan Library (excerpt)



How to Do Automatic Program Understanding ?

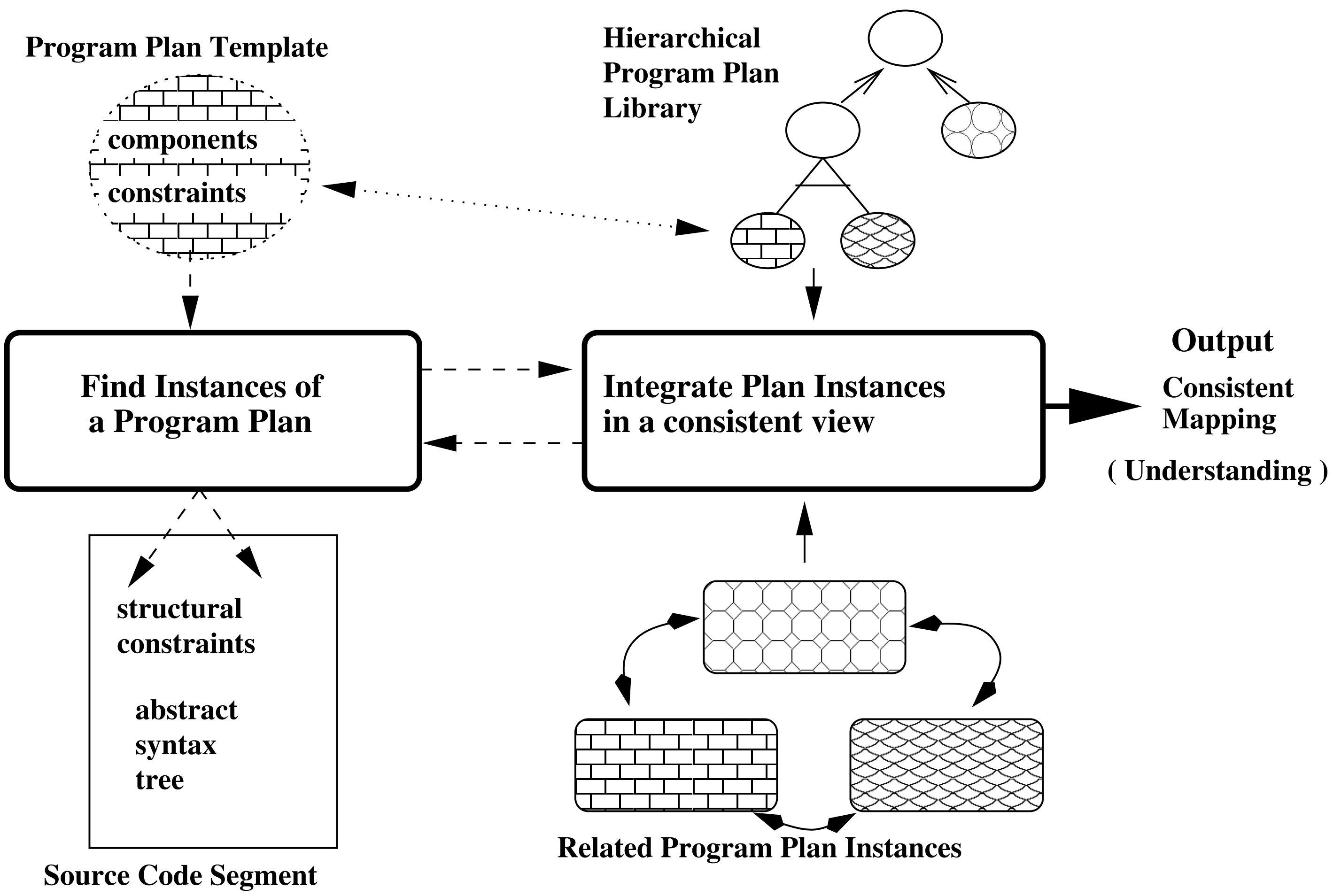
→ Directly solve the problem with a specifically designed algorithm.

- Does a polynomial algorithm exist ?

→ Generate heuristic solutions to the problem and select one.

- How do we generate these solutions ?
- How do we select amongst possible solutions ?
- Can this heuristic method scale for real/useful cases ?

Typical Program Understanding in Two Parts



Selected Past Approaches for Understanding

→ CONCEPT RECOGNIZER

- Abstracted plans consist of components and constraints
- Source is abstract syntax tree with constraint annotations

→ DECODE Index-based Recognizer extends CONCEPT RECOGNIZER

- Indices (memory keys) control candidate plan selection

→ Graph Grammar Parser

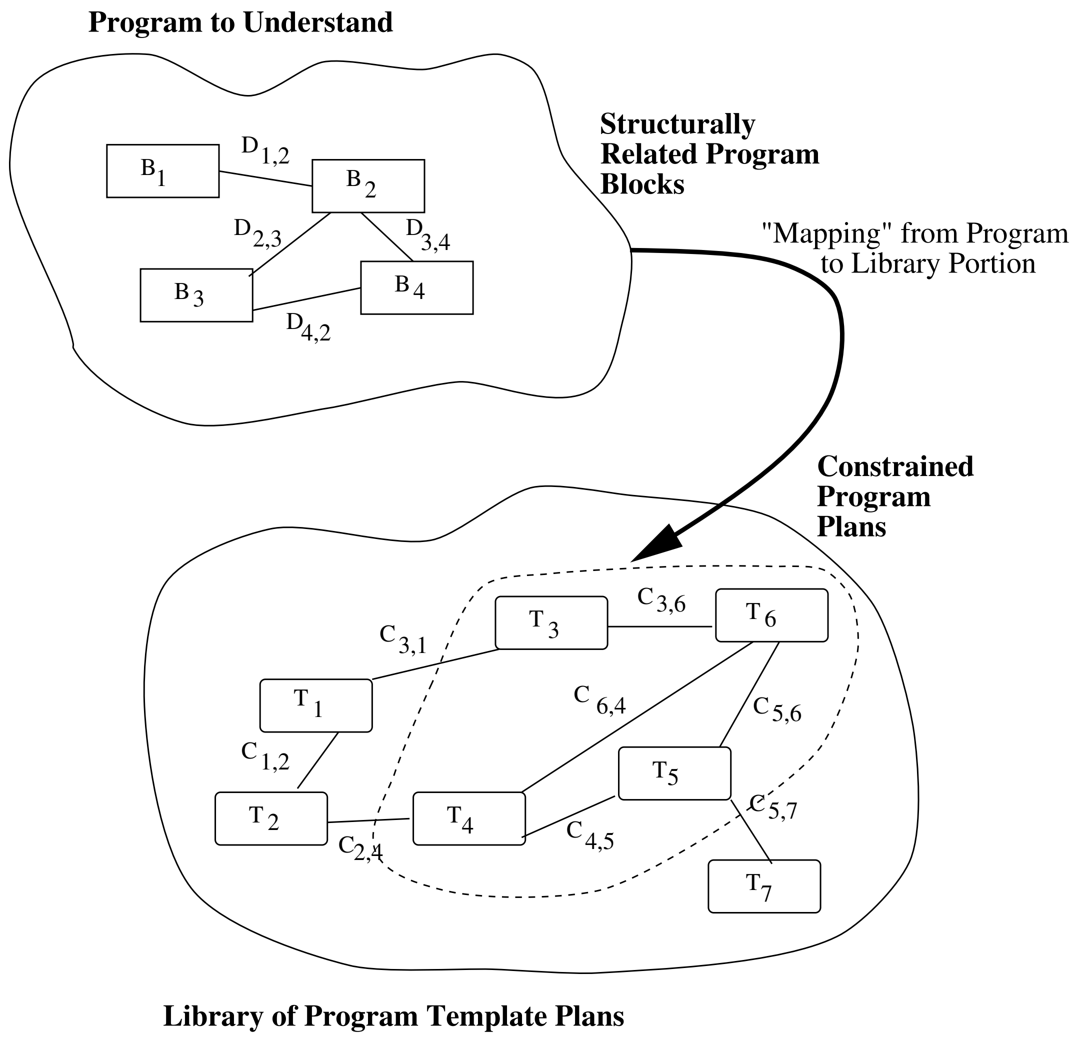
- Library components rep'd as graph grammars
- Source program rep'd as annotated flow graph
- Constrained parsing of flow graph gives explanation

Simplify Program Understanding Problem

- Want to extract minimum required problem.
- Generate simplest case including all shared features.

$\Rightarrow$ If simplified version computationally hard, then so is a more general version.

Simple Program Understanding Problem (SPU)



SPU is Representative of Past Work

→ Library: set of constraint graphs for component combination

- Abstracted, constrained, structured cliché representation

→ Source Program: annotated control and data flow graph of program blocks

- Explicit structural constraint information added to intermediate representation

→ Solution Strategy to identify mapping

- Solution must support structural constraints; satisfy component constraints

SPU is NP-hard

→ **Subgraph Isomorphism (SI)**, problem to determine if a particular graph G "contains" another graph H is NP-hard.

→ NP-hard means worst-case exponential computation, inevitable for any heuristic.

Sketch of NP-hard proof for SPU ...

→ **SI** can be transformed to Simple Program Understanding (SPU):

- Consider the library of program plans as graph G.
- Consider the source program to explain as graph H.

→ This transformation for G and H can be done in time polynomial in the combined size of the respective library and program.

Is a Simpler Problem still NP-hard ?

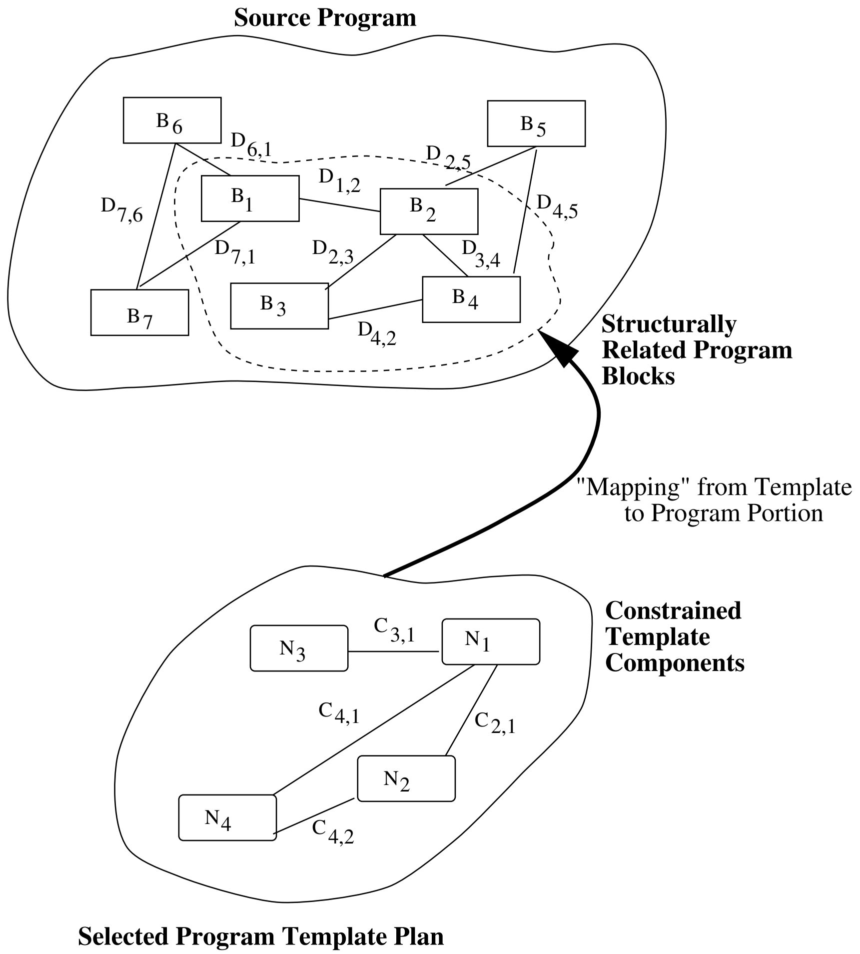
- Understanding involves explaining an entire legacy source.
- Can we explain only a segment of the source ?
- We can look for instances of a particular plan.
- Is this computationally easier ?

Simplify Template Matching Problem

- Want to extract minimum required problem.
- Generate simplest case including all shared features.

$\Rightarrow$ If simplified version computationally hard, then so is a more general version.

Simple **Program Template Matching Problem (SMAP)**



SMAP is Representative of Past Work

→ Program Plan Template (Cliché)

- Abstracted, constrained cliché components

→ Source Program: annotated control and data flow graph of program blocks

- Explicit structural constraint information added to intermediate representation

→ Solution Strategy

- Solution must satisfy template component constraints; support structural constraints

SMAP is NP-hard

- $\rightarrow$ **Subgraph-Isomorphism** is reducible to Simple Program Template Matching (SMAP).
- $\rightarrow$ The transformation is similar to SPU and is also polynomial.

So What Can We Do ?

- $\rightarrow$ Simplified problem structures resemble known framework.
- $\rightarrow$ Can this methodology help us ?

Unifying Past Approaches: Constraint Satisfaction

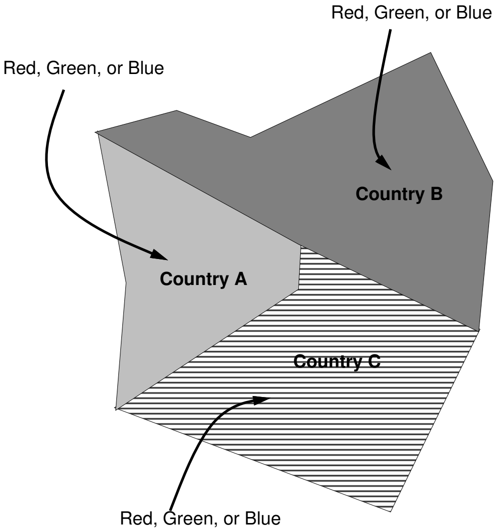


Figure 1: Map Color Example.

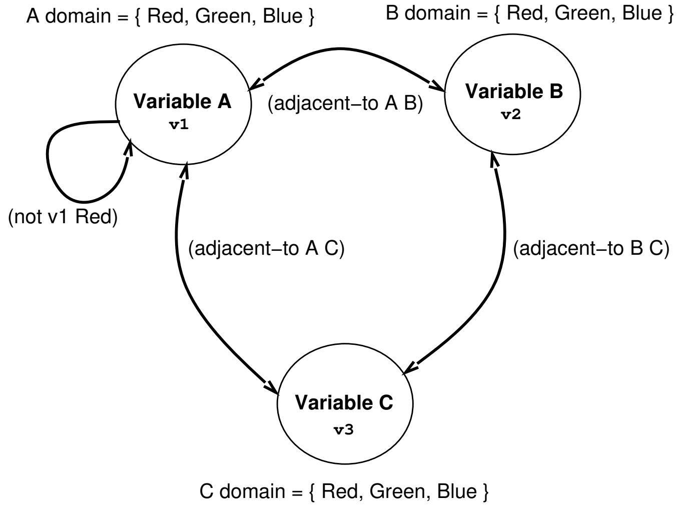


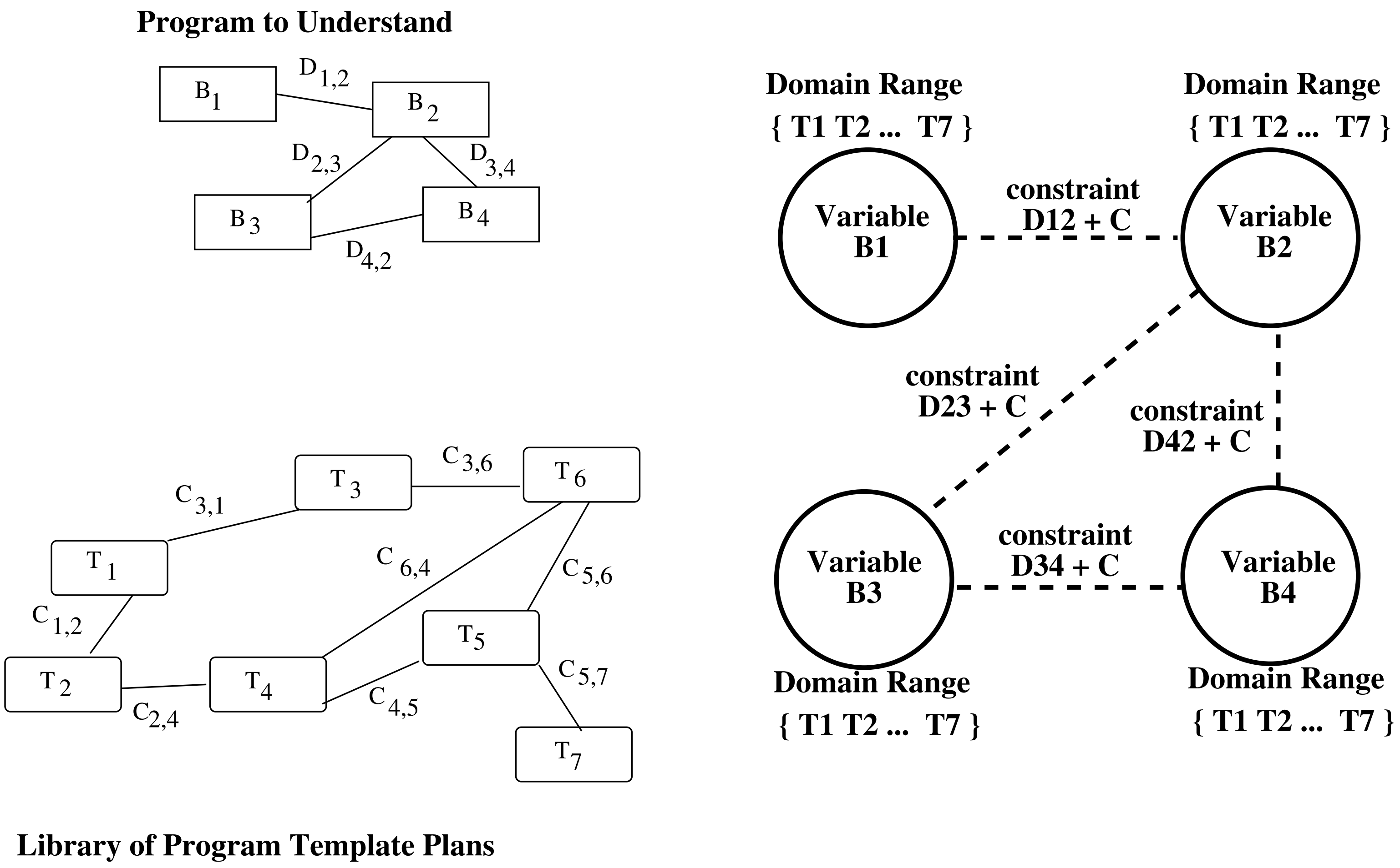
Figure 2: Map Color CSP.

→ Known methods: Local/Global Search; Constraint Propagation

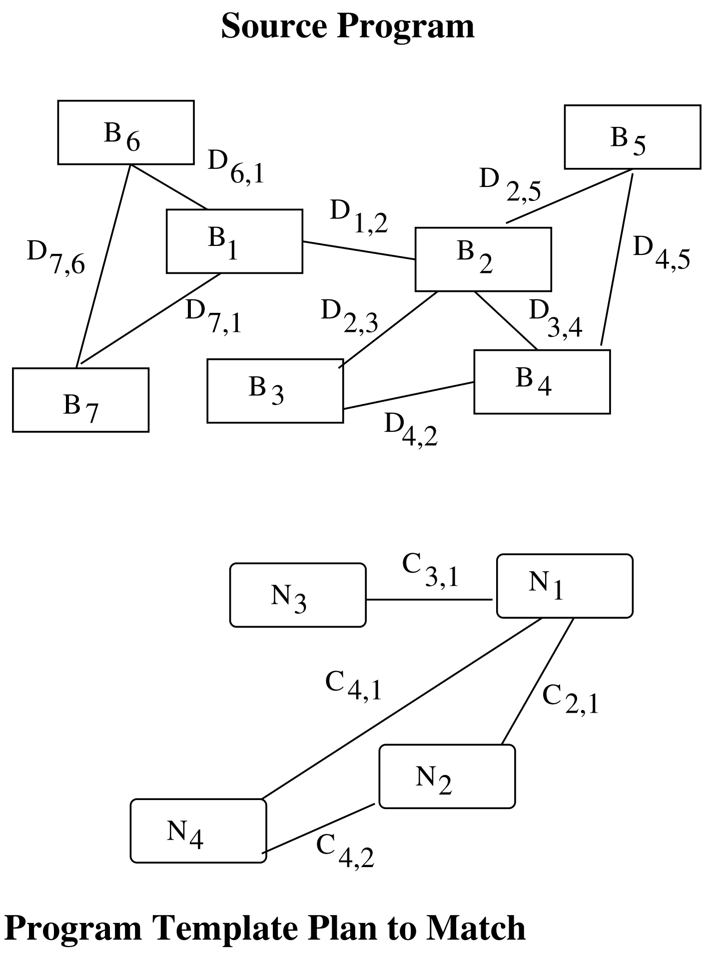
→ Increased problem knowledge ⇒ well-constrained problem

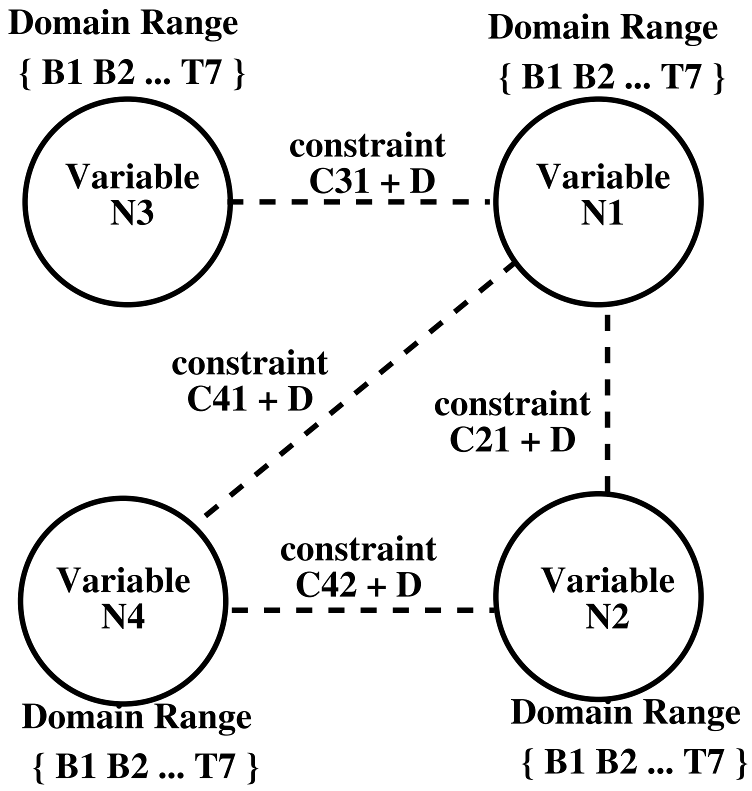
⇒ improved performance potential

SPU becomes PU-CSP



SMAP becomes MAP-CSP





Some MAP-CSP Implementation Results

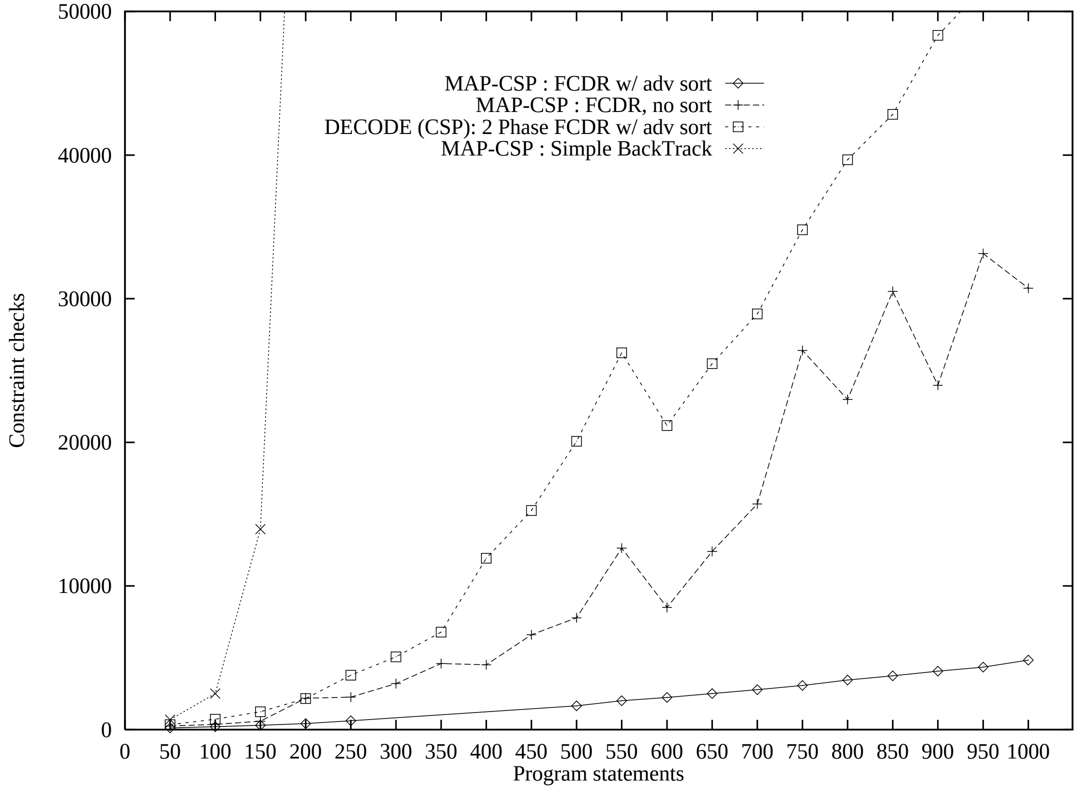


Figure 3: Matching a Template with 9 components, 20 constraints.

Conclusions

- Program Understanding is NP-hard
- Constraint Satisfaction offers a promising avenue for unifying previous heuristic approaches
- Experimental results suggest careful constraint application can be effective for SMAP/MAP-CSP in instances of $>$ 800 source lines

Ongoing Work

- Overall (integrated) understanding implementation
- Hierarchical constraint application algorithm
- Extended experiments with MAP-CSP and PU-CSP
- Looking for large, structured datasets/sources