Accelerating Array Constraints in Symbolic Execution

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*The first two authors contributed equally to this paper

What is Symbolic Execution?

```
int bad_abs(int x) {
    if(x < 0)
        return -x;
    if(x == 1234)
        return -x;
    return x;
}
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X = ?

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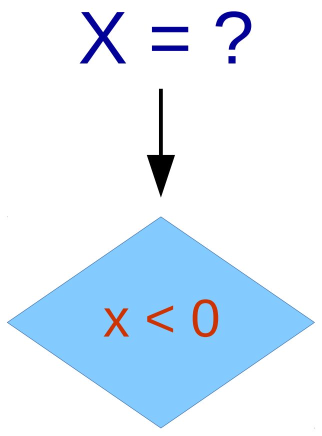

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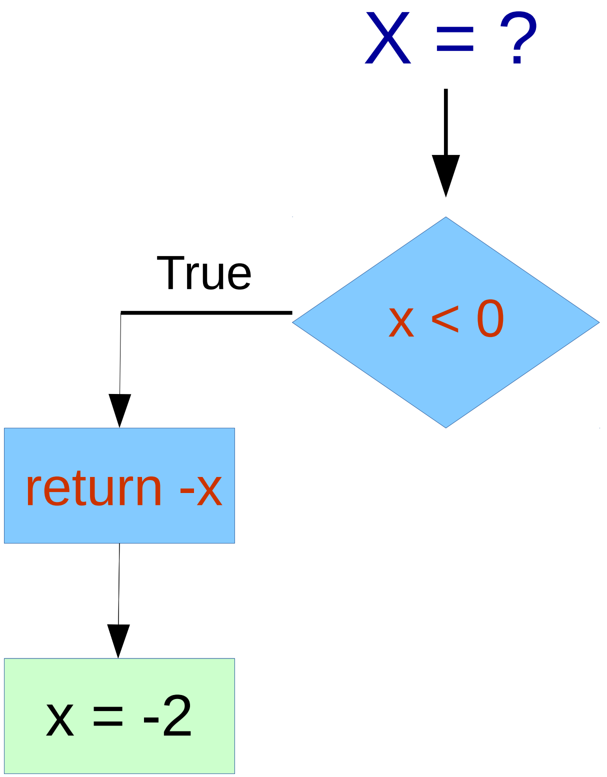

Test1.out

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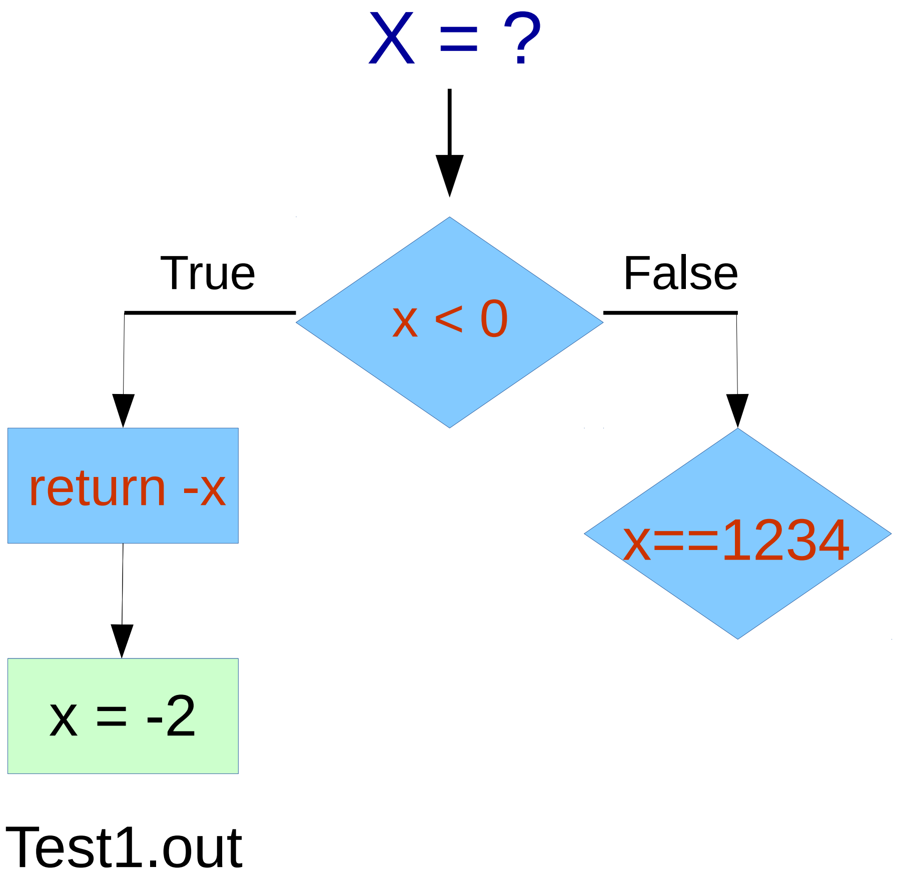

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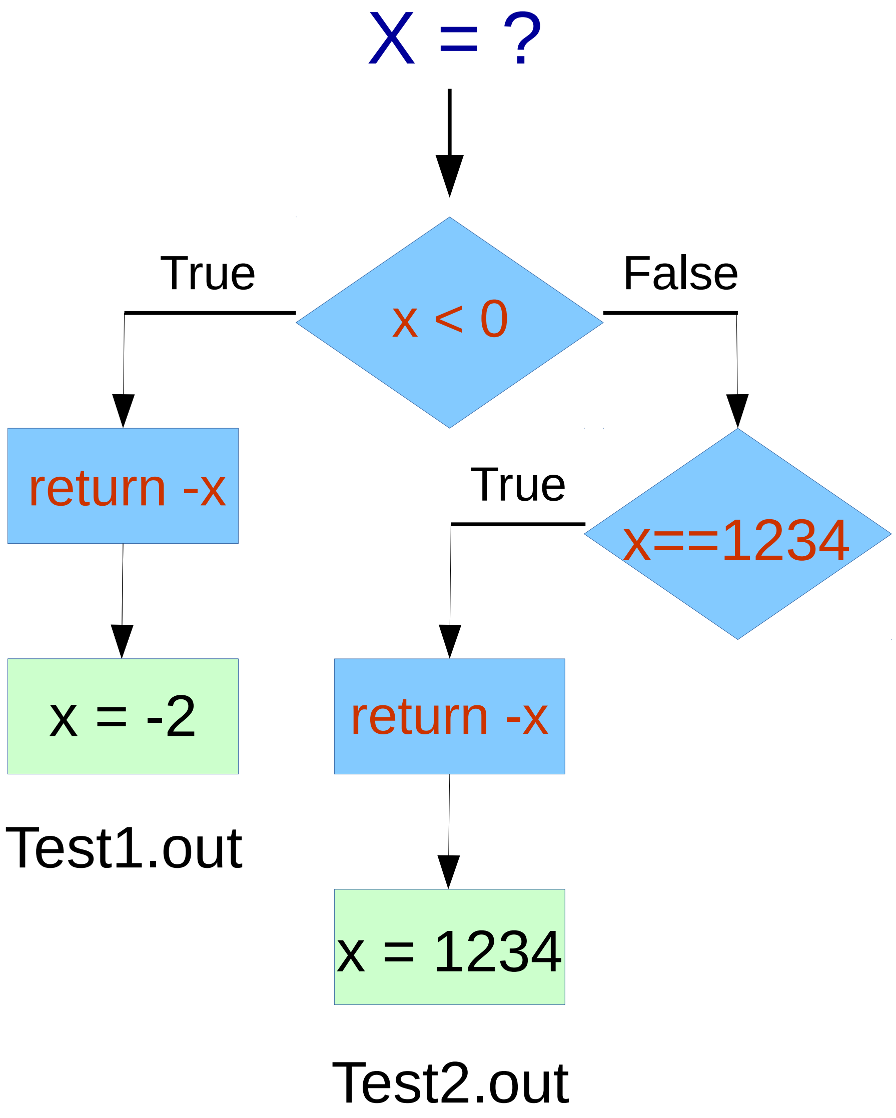

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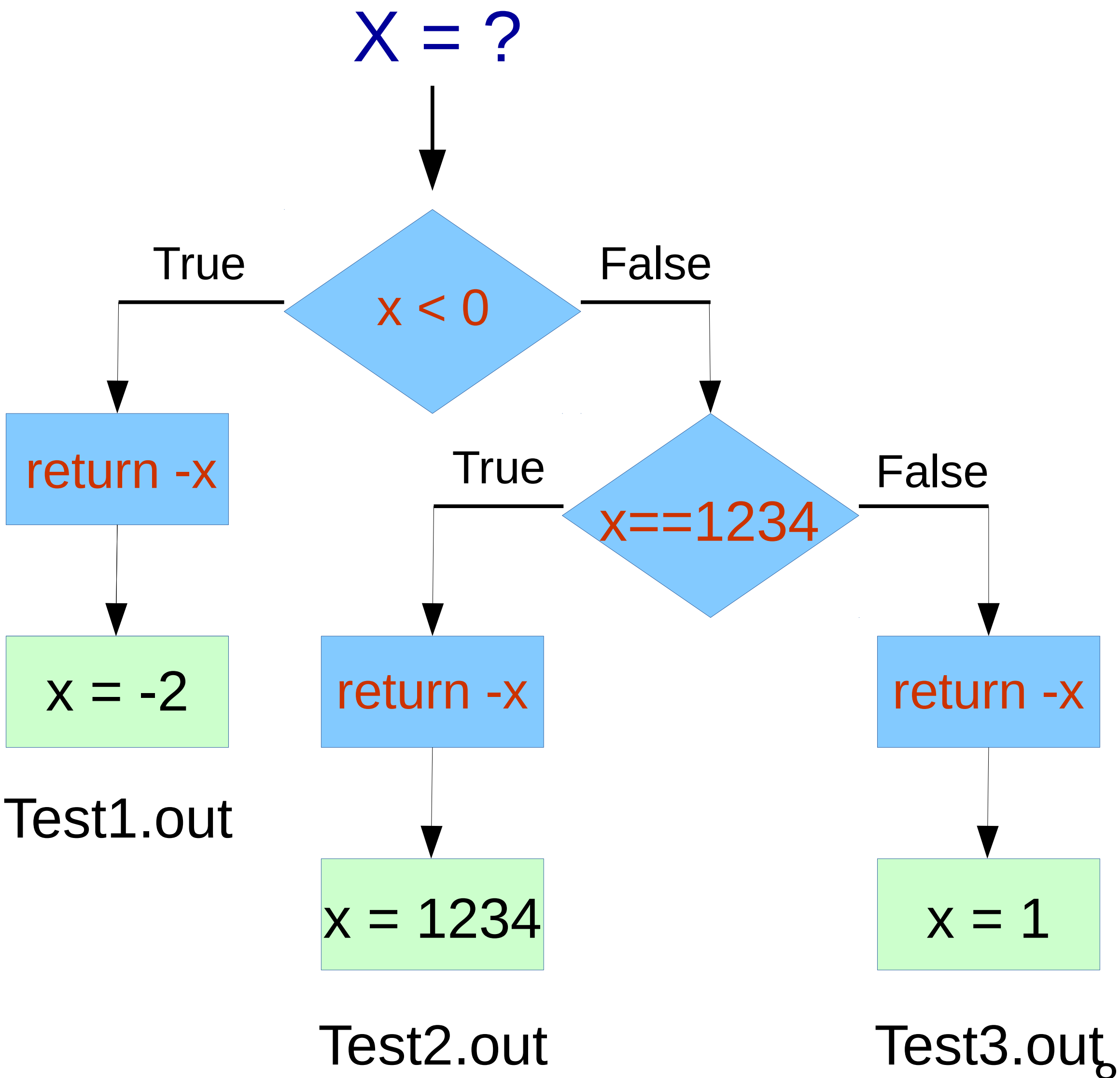

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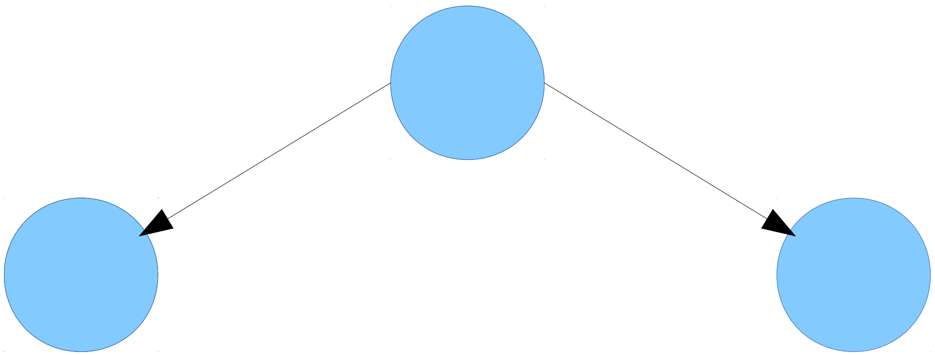

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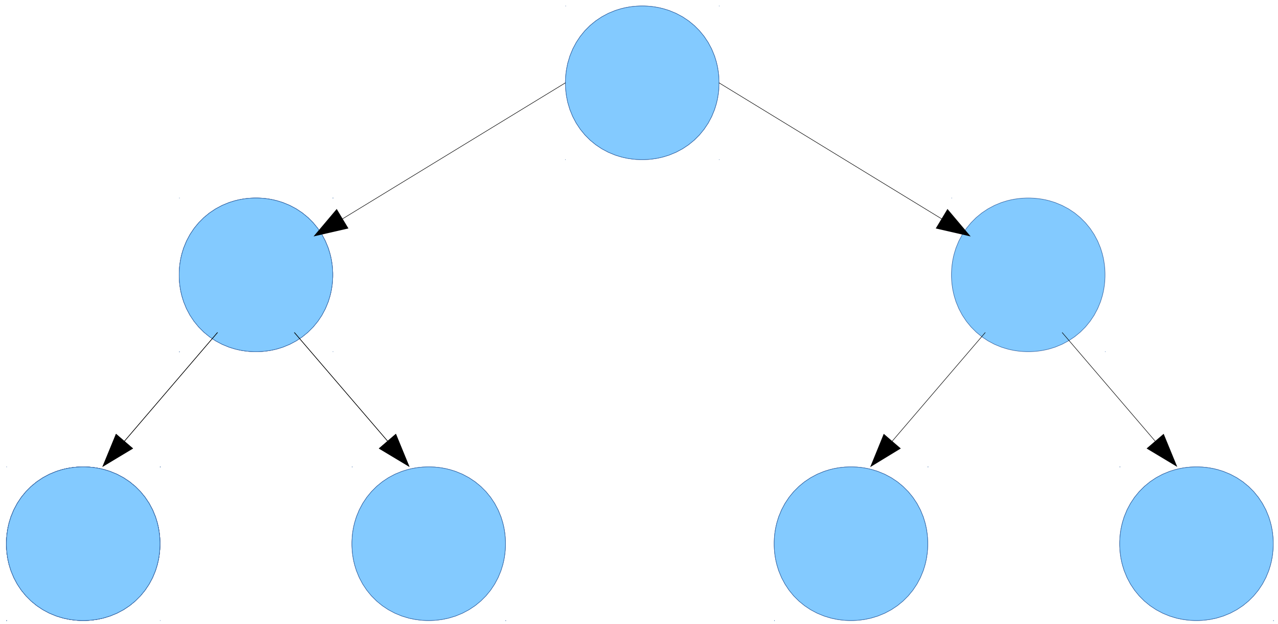

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SMT SOLVER

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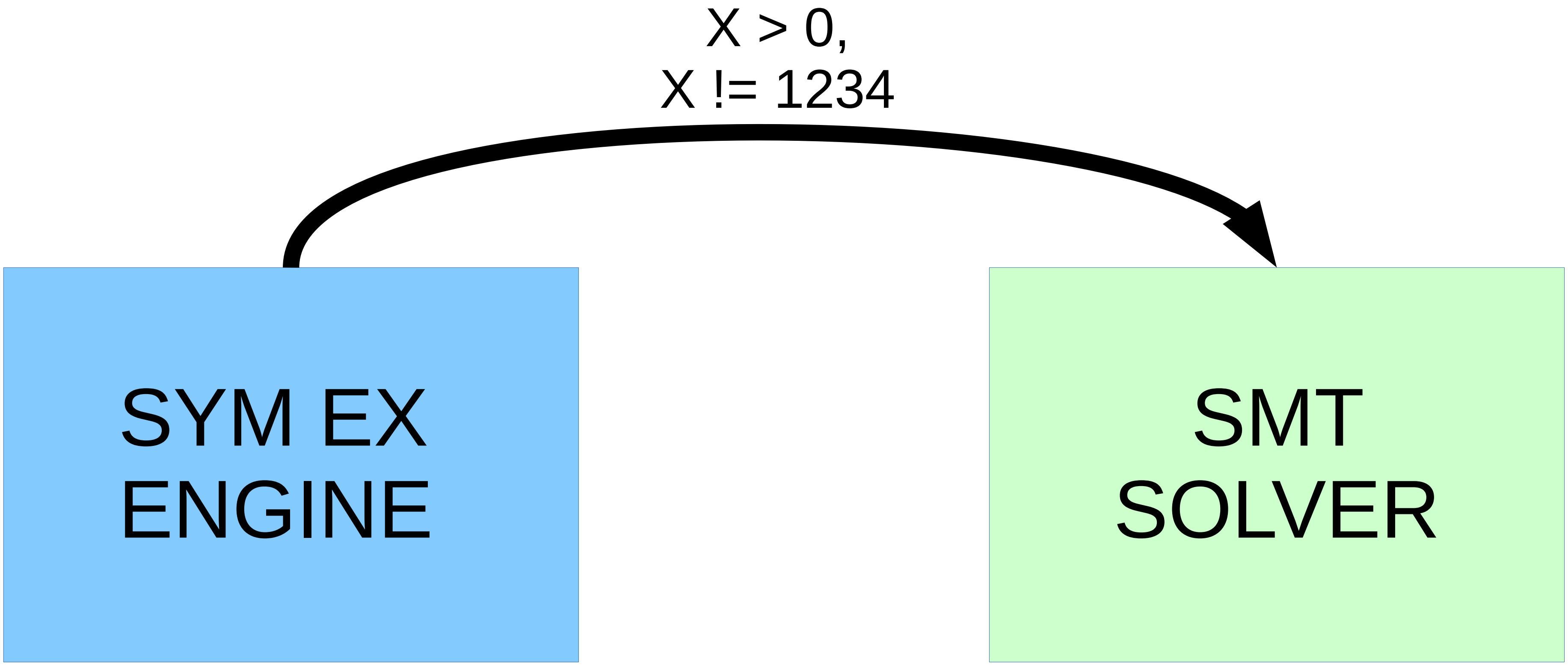

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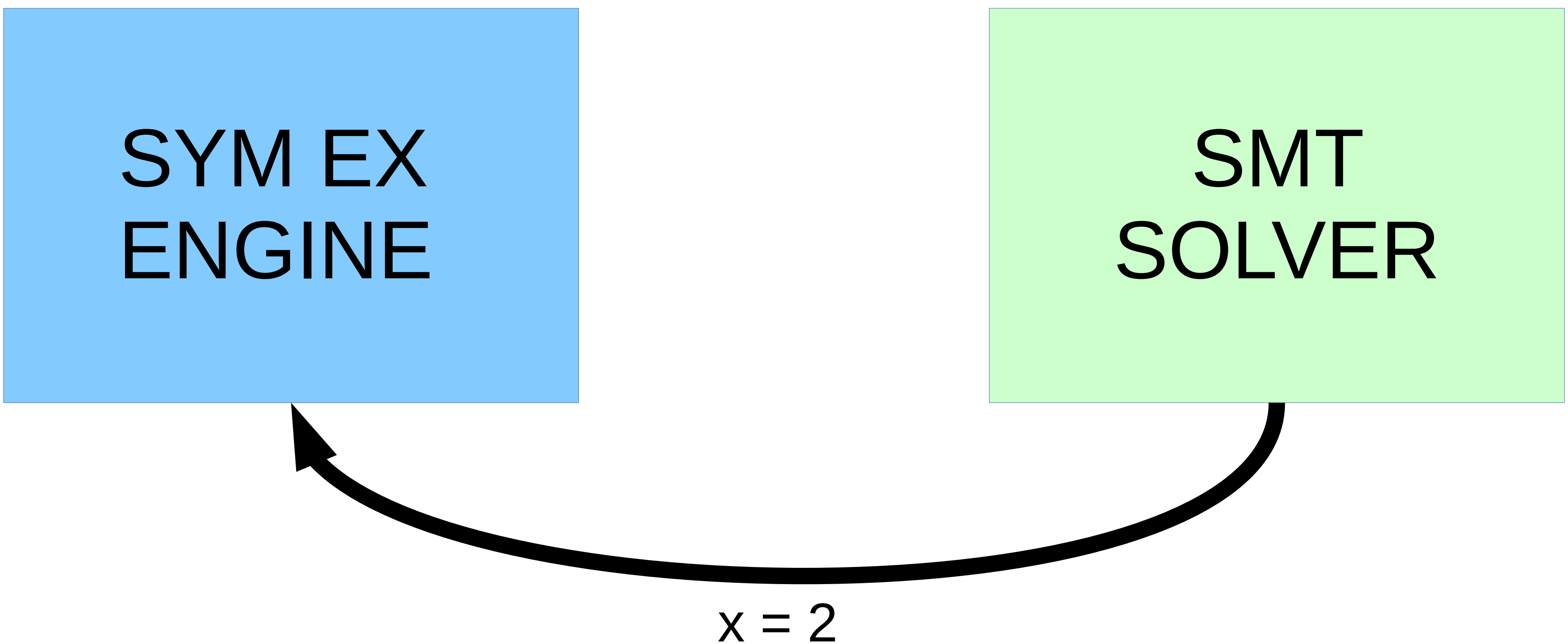

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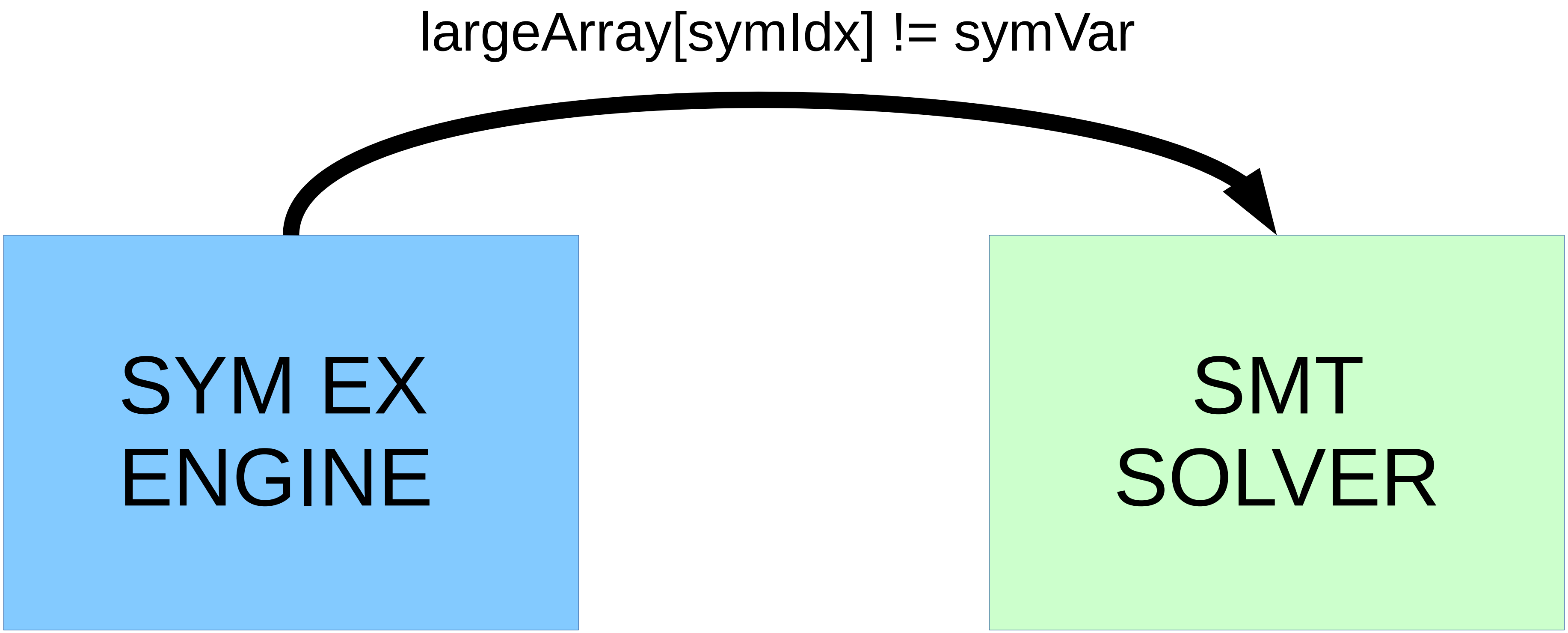

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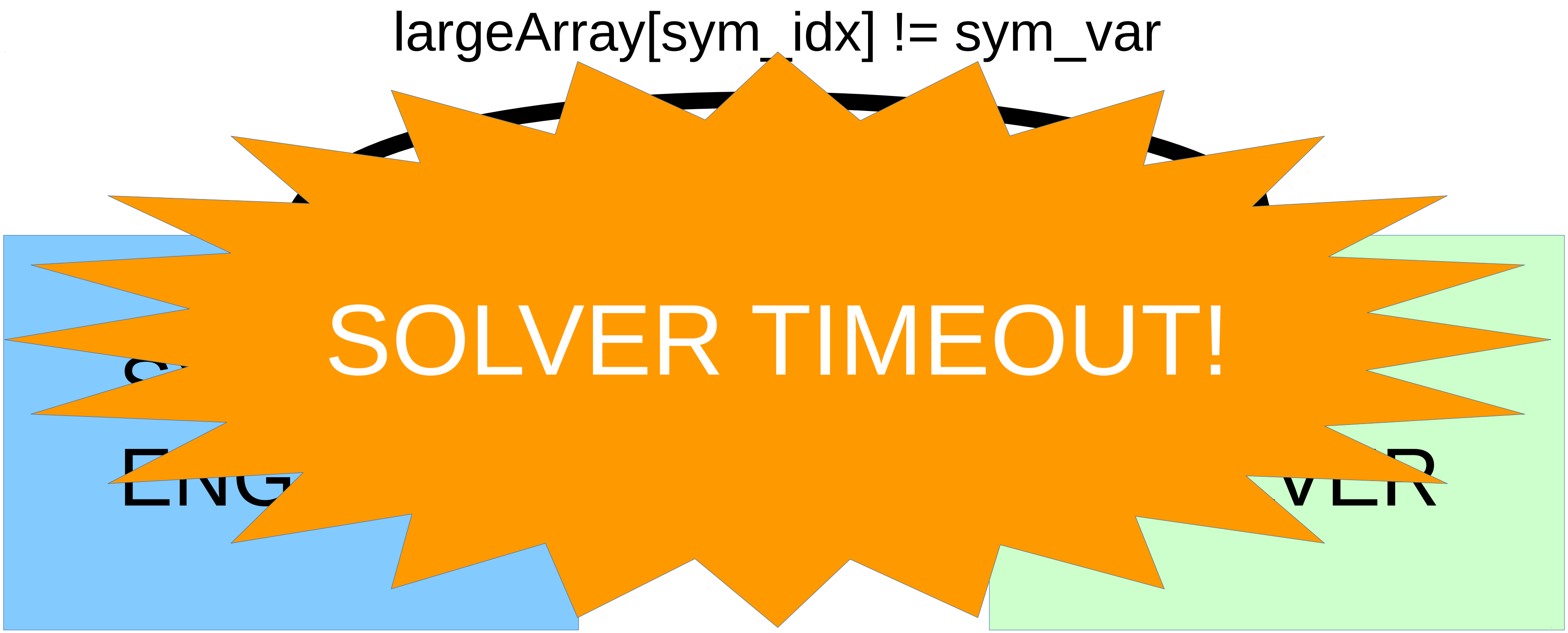

A Challenging Example: BC

```
Void tokenMatch(char *input) {
  Unsigned currState = 0;
  Char charPtr = input;
  Do {
    Char currClass = equivClass[*charPtr];
    if(accept[currState]) {
      LastAcceptState = currState;
      LastAcceptPos = charPtr;
    }
    while(check[base[currState] + currClass] != currState) {
      CurrState = def[currState];
      if(currState >= 298) {CurrClass = meta[currClass];}
    }
    CurrState = next[base[currState] + currClass]; charPtr++;
  } while(base[currState] != 526);
}
```

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  Char charPtr = input;
  Do {
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      LastAcceptState = currState;
      LastAcceptPos = charPtr;
    }
    while(check[base[currState] + currClass] != currState)
      CurrState = def[currState];
      if(currState >= 298) {CurrClass = meta[currClass];}
    }
    CurrState = next[base[currState] + currClass]; charPtr++;
  } while(base[currState] != 526);
}
```

How does Symbolic Execution handle array reads?

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int small[5] = {0,3,2,2,2};
if(small[sym_idx] == 2) {...}
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- **Create a variable and assign its value for each offset**
  - small_0 = 0 ∧ small_1 = 3 ∧ small_2 = 2 ∧ small_3 = 3 ∧ small_4 = 2

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  - $small\_0 = 0 \land small\_1 = 3 \land small\_2 = 2 \land small\_3 = 3 \land small\_4 = 2$
- **Add a constraint for the conditional**
  - val == small[sym_idx] == 2

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  - small_0 = 0 ∧ small_1 = 3 ∧ small_2 = 2 ∧ small_3 = 3 ∧ small_4 = 2
- Add a constraint for the conditional
  - val == small[sym_idx] == 2
- **Handle the read operation**
  - sym_idx = 0 → val = small_0 ∧ sym_idx = 1 → val = small_1 ∧
    sym_idx = 2 → val = small_2 ∧ sym_idx = 3 → val = small_3 ∧
    sym_idx = 4 → val = small_4

How does Symbolic Execution handle array reads?

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, 62, -1, -1, -1, 63,
52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27,
28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50,
51, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1
};

unsigned isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= 0)
        return 1;
    else return 0;
}
```

How does Symbolic Execution handle array reads?

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, 62, -1, -1, -1, 63,
52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27,
28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50,
51, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
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    if(k > 255)
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    else return 0;
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How does Symbolic Execution handle array reads?

b64[0]=-1 ∧ b64[1]=-1 ∧ b64[2]=-1 ∧ b64[3]=-1 ∧ b64[4]=-1 ∧ b64[5]=-1 ∧ b64[6]=-1 ∧ b64[7]=-1 ∧ b64[8]=-1 ∧ b64[9]=-1 ∧ b64[10]=-1 ∧ b64[11]=-1 ∧ b64[12]=-1 ∧ b64[13]=-1 ∧ b64[14]=-1 ∧ b64[15]=-1 ∧ b64[16]=-1 ∧ b64[17]=-1 ∧ b64[18]=-1 ∧ b64[19]=-1 ∧ b64[20]=-1 ∧ b64[21]=-1 ∧ b64[22]=-1 ∧ b64[23]=-1 ∧ b64[24]=-1 ∧ b64[25]=-1 ∧ b64[26]=-1 ∧ b64[27]=-1 ∧ b64[28]=-1 ∧ b64[29]=-1 ∧ b64[30]=-1 ∧ b64[31]=-1 ∧ b64[32]=-1 ∧ b64[33]=-1 ∧ b64[34]=-1 ∧ b64[35]=-1 ∧ b64[36]=-1 ∧ b64[37]=-1 ∧ b64[38]=-1 ∧ b64[39]=-1 ∧ b64[40]=-1 ∧ b64[41]=-1 ∧ b64[42]=-1 ∧ b64[43]=62 ∧ b64[44]=-1 ∧ b64[45]=-1 ∧ b64[46]=-1 ∧ b64[47]=63 ∧ b64[48]=52 ∧ b64[49]=53 ∧ b64[50]=54 ∧ b64[51]=55 ∧ b64[52]=56 ∧ b64[53]=57 ∧ b64[54]=58 ∧ b64[55]=59 ∧ b64[56]=60 ∧ b64[57]=61 ∧ b64[58]=-1 ∧ b64[59]=-1 ∧ b64[60]=-1 ∧ b64[61]=-1 ∧ b64[62]=-1 ∧ b64[63]=-1 ∧ b64[64]=-1 ∧ b64[65]=0 ∧ b64[66]=1 ∧ b64[67]=2 ∧ b64[68]=3 ∧ b64[69]=4 ∧ b64[70]=5 ∧ b64[71]=6 ∧ b64[72]=7 ∧ b64[73]=8 ∧ b64[74]=9 ∧ b64[75]=10 ∧ b64[76]=11 ∧ b64[77]=12 ∧ b64[78]=13 ∧ b64[79]=14 ∧ b64[80]=15 ∧ b64[81]=16 ∧ b64[82]=17 ∧ b64[83]=18 ∧ b64[84]=19 ∧ b64[85]=20 ∧ b64[86]=21 ∧ b64[87]=22 ∧ b64[88]=23 ∧ b64[89]=24 ∧ b64[90]=25 ∧ b64[91]=-1 ∧ b64[92]=-1 ∧ b64[93]=-1 ∧ b64[94]=-1 ∧ b64[95]=-1 ∧ b64[96]=-1 ∧ b64[97]=26 ∧ b64[98]=27 ∧ b64[99]=28 ∧ b64[100]=29 ∧ b64[101]=30 ∧ b64[102]=31 ∧ b64[103]=32 ∧ b64[104]=33 ∧ b64[105]=34 ∧ b64[106]=35 ∧ b64[107]=36 ∧ b64[108]=37 ∧ b64[109]=38 ∧ b64[110]=39 ∧ b64[111]=40 ∧ b64[112]=41 ∧ b64[113]=42 ∧ b64[114]=43 ∧ b64[115]=44 ∧ b64[116]=45 ∧ b64[117]=46 ∧ b64[118]=47 ∧ b64[119]=48 ∧ b64[120]=49 ∧ b64[121]=50 ∧ b64[122]=51 ∧ b64[123]=-1 ∧ b64[124]=-1 ∧ b64[125]=-1 ∧ b64[126]=-1 ∧ b64[127]=-1 ∧ b64[128]=-1 ∧ b64[129]=-1 ∧ b64[130]=-1 ∧ b64[131]=-1 ∧ b64[132]=-1 ∧ b64[133]=-1 ∧ b64[134]=-1 ∧ b64[135]=-1 ∧ b64[136]=-1 ∧ b64[137]=-1 ∧ b64[138]=-1 ∧ b64[139]=-1 ∧ b64[140]=-1 ∧ b64[141]=-1 ∧ b64[142]=-1 ∧ b64[143]=-1 ∧ b64[144]=-1 ∧ b64[145]=-1 ∧ b64[146]=-1 ∧ b64[147]=-1 ∧ b64[148]=-1 ∧ b64[149]=-1 ∧ b64[150]=-1 ∧ b64[151]=-1 ∧ b64[152]=-1 ∧ b64[153]=-1 ∧ b64[154]=-1 ∧ b64[155]=-1 ∧ b64[156]=-1 ∧ b64[157]=-1 ∧ b64[158]=-1 ∧ b64[159]=-1 ∧ b64[160]=-1 ∧ b64[161]=-1 ∧ b64[162]=-1 ∧ b64[163]=-1 ∧ b64[164]=-1 ∧ b64[165]=-1 ∧ b64[166]=-1 ∧ b64[167]=-1 ∧ b64[168]=-1 ∧ b64[169]=-1 ∧ b64[170]=-1 ∧ b64[171]=-1 ∧ b64[172]=-1 ∧ b64[173]=-1 ∧ b64[174]=-1 ∧ b64[175]=-1 ∧ b64[176]=-1 ∧ b64[177]=-1 ∧ b64[178]=-1 ∧ b64[179]=-1 ∧ b64[180]=-1 ∧ b64[181]=-1 ∧ b64[182]=-1 ∧ b64[183]=-1 ∧ b64[184]=-1 ∧ b64[185]=-1 ∧ b64[186]=-1 ∧ b64[187]=-1 ∧ b64[188]=-1 ∧ b64[189]=-1 ∧ b64[190]=-1 ∧ b64[191]=-1 ∧ b64[192]=-1 ∧ b64[193]=-1 ∧ b64[194]=-1 ∧ b64[195]=-1 ∧ b64[196]=-1 ∧ b64[197]=-1 ∧ b64[198]=-1 ∧ b64[199]=-1 ∧ b64[200]=-1 ∧ b64[201]=-1 ∧ b64[202]=-1 ∧ b64[203]=-1 ∧ b64[204]=-1 ∧ b64[205]=-1 ∧ b64[206]=-1 ∧ b64[207]=-1 ∧ b64[208]=-1 ∧ b64[209]=-1 ∧ b64[210]=-1 ∧ b64[211]=-1 ∧ b64[212]=-1 ∧ b64[213]=-1 ∧ b64[214]=-1 ∧ b64[215]=-1 ∧ b64[216]=-1 ∧ b64[217]=-1 ∧ b64[218]=-1 ∧ b64[219]=-1 ∧ b64[220]=-1 ∧ b64[221]=-1 ∧ b64[222]=-1 ∧ b64[223]=-1 ∧ b64[224]=-1 ∧ b64[225]=-1 ∧ b64[226]=-1 ∧ b64[227]=-1 ∧ b64[228]=-1 ∧ b64[229]=-1 ∧ b64[230]=-1 ∧ b64[231]=-1 ∧ b64[232]=-1 ∧ b64[233]=-1 ∧ b64[234]=-1 ∧ b64[235]=-1 ∧ b64[236]=-1 ∧ b64[237]=-1 ∧ b64[238]=-1 ∧ b64[239]=-1 ∧ b64[240]=-1 ∧ b64[241]=-1 ∧ b64[242]=-1 ∧ b64[243]=-1 ∧ b64[244]=-1 ∧ b64[245]=-1 ∧ b64[246]=-1 ∧ b64[247]=-1 ∧ b64[248]=-1 ∧ b64[249]=-1 ∧ b64[250]=-1 ∧ b64[251]=-1 ∧ b64[252]=-1 ∧ b64[253]=-1 ∧ b64[254]=-1 ∧ b64[255]=-1 ∧

How does Symbolic Execution handle array reads?

$$\boxed{B64k \geq 0 \land k \leq 255}$$

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k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ k=2 → b64k=b64[2] ∧ k=3 → b64k=b64[3] ∧ k=4 → b64k=b64[4] ∧ k=5 → b64k=b64[5] ∧ k=6 → b64k=b64[6] ∧ k=7 → b64k=b64[7] ∧ k=8 →
b64k=b64[8] ∧ k=9 → b64k=b64[9] ∧ k=10 → b64k=b64[10] ∧ k=11 → b64k=b64[11] ∧ k=12 → b64k=b64[12] ∧ k=13 → b64k=b64[13] ∧ k=14 → b64k=b64[14] ∧ k=15 → b64k=b64[15] ∧ k=16 →
b64k=b64[16] ∧ k=17 → b64k=b64[17] ∧ k=18 → b64k=b64[18] ∧ k=19 → b64k=b64[19] ∧ k=20 → b64k=b64[20] ∧ k=21 → b64k=b64[21] ∧ k=22 → b64k=b64[22] ∧ k=23 → b64k=b64[23] ∧
k=24 → b64k=b64[24] ∧ k=25 → b64k=b64[25] ∧ k=26 → b64k=b64[26] ∧ k=27 → b64k=b64[27] ∧ k=28 → b64k=b64[28] ∧ k=29 → b64k=b64[29] ∧ k=30 → b64k=b64[30] ∧ k=31 →
b64k=b64[31] ∧ k=32 → b64k=b64[32] ∧ k=33 → b64k=b64[33] ∧ k=34 → b64k=b64[34] ∧ k=35 → b64k=b64[35] ∧ k=36 → b64k=b64[36] ∧ k=37 → b64k=b64[37] ∧ k=38 → b64k=b64[38] ∧
k=39 → b64k=b64[39] ∧ k=40 → b64k=b64[40] ∧ k=41 → b64k=b64[41] ∧ k=42 → b64k=b64[42] ∧ k=43 → b64k=b64[43] ∧ k=44 → b64k=b64[44] ∧ k=45 → b64k=b64[45] ∧ k=46 →
b64k=b64[46] ∧ k=47 → b64k=b64[47] ∧ k=48 → b64k=b64[48] ∧ k=49 → b64k=b64[49] ∧ k=50 → b64k=b64[50] ∧ k=51 → b64k=b64[51] ∧ k=52 → b64k=b64[52] ∧ k=53 → b64k=b64[53] ∧
k=54 → b64k=b64[54] ∧ k=55 → b64k=b64[55] ∧ k=56 → b64k=b64[56] ∧ k=57 → b64k=b64[57] ∧ k=58 → b64k=b64[58] ∧ k=59 → b64k=b64[59] ∧ k=60 → b64k=b64[60] ∧ k=61 →
b64k=b64[61] ∧ k=62 → b64k=b64[62] ∧ k=63 → b64k=b64[63] ∧ k=64 → b64k=b64[64] ∧ k=65 → b64k=b64[65] ∧ k=66 → b64k=b64[66] ∧ k=67 → b64k=b64[67] ∧ k=68 → b64k=b64[68] ∧
k=69 → b64k=b64[69] ∧ k=70 → b64k=b64[70] ∧ k=71 → b64k=b64[71] ∧ k=72 → b64k=b64[72] ∧ k=73 → b64k=b64[73] ∧ k=74 → b64k=b64[74] ∧ k=75 → b64k=b64[75] ∧ k=76 →
b64k=b64[76] ∧ k=77 → b64k=b64[77] ∧ k=78 → b64k=b64[78] ∧ k=79 → b64k=b64[79] ∧ k=80 → b64k=b64[80] ∧ k=81 → b64k=b64[81] ∧ k=82 → b64k=b64[82] ∧ k=83 → b64k=b64[83] ∧
k=84 → b64k=b64[84] ∧ k=85 → b64k=b64[85] ∧ k=86 → b64k=b64[86] ∧ k=87 → b64k=b64[87] ∧ k=88 → b64k=b64[88] ∧ k=89 → b64k=b64[89] ∧ k=90 → b64k=b64[90] ∧ k=91 →
b64k=b64[91] ∧ k=92 → b64k=b64[92] ∧ k=93 → b64k=b64[93] ∧ k=94 → b64k=b64[94] ∧ k=95 → b64k=b64[95] ∧ k=96 → b64k=b64[96] ∧ k=97 → b64k=b64[97] ∧ k=98 → b64k=b64[98] ∧
k=99 → b64k=b64[99] ∧ k=100 → b64k=b64[100] ∧ k=101 → b64k=b64[101] ∧ k=102 → b64k=b64[102] ∧ k=103 → b64k=b64[103] ∧ k=104 → b64k=b64[104] ∧ k=105 → b64k=b64[105] ∧
k=106 → b64k=b64[106] ∧ k=107 → b64k=b64[107] ∧ k=108 → b64k=b64[108] ∧ k=109 → b64k=b64[109] ∧ k=110 → b64k=b64[110] ∧ k=111 → b64k=b64[111] ∧ k=112 → b64k=b64[112] ∧
k=113 → b64k=b64[113] ∧ k=114 → b64k=b64[114] ∧ k=115 → b64k=b64[115] ∧ k=116 → b64k=b64[116] ∧ k=117 → b64k=b64[117] ∧ k=118 → b64k=b64[118] ∧ k=119 → b64k=b64[119] ∧
k=120 → b64k=b64[120] ∧ k=121 → b64k=b64[121] ∧ k=122 → b64k=b64[122] ∧ k=123 → b64k=b64[123] ∧ k=124 → b64k=b64[124] ∧ k=125 → b64k=b64[125] ∧ k=126 → b64k=b64[126] ∧
k=127 → b64k=b64[127] ∧ k=128 → b64k=b64[128] ∧ k=129 → b64k=b64[129] ∧ k=130 → b64k=b64[130] ∧ k=131 → b64k=b64[131] ∧ k=132 → b64k=b64[132] ∧ k=133 → b64k=b64[133] ∧
k=134 → b64k=b64[134] ∧ k=135 → b64k=b64[135] ∧ k=136 → b64k=b64[136] ∧ k=137 → b64k=b64[137] ∧ k=138 → b64k=b64[138] ∧ k=139 → b64k=b64[139] ∧ k=140 → b64k=b64[140] ∧
k=141 → b64k=b64[141] ∧ k=142 → b64k=b64[142] ∧ k=143 → b64k=b64[143] ∧ k=144 → b64k=b64[144] ∧ k=145 → b64k=b64[145] ∧ k=146 → b64k=b64[146] ∧ k=147 → b64k=b64[147] ∧
k=148 → b64k=b64[148] ∧ k=149 → b64k=b64[149] ∧ k=150 → b64k=b64[150] ∧ k=151 → b64k=b64[151] ∧ k=152 → b64k=b64[152] ∧ k=153 → b64k=b64[153] ∧ k=154 → b64k=b64[154] ∧
k=155 → b64k=b64[155] ∧ k=156 → b64k=b64[156] ∧ k=157 → b64k=b64[157] ∧ k=158 → b64k=b64[158] ∧ k=159 → b64k=b64[159] ∧ k=160 → b64k=b64[160] ∧ k=161 → b64k=b64[161] ∧
k=162 → b64k=b64[162] ∧ k=163 → b64k=b64[163] ∧ k=164 → b64k=b64[164] ∧ k=165 → b64k=b64[165] ∧ k=166 → b64k=b64[166] ∧ k=167 → b64k=b64[167] ∧ k=168 → b64k=b64[168] ∧
k=169 → b64k=b64[169] ∧ k=170 → b64k=b64[170] ∧ k=171 → b64k=b64[171] ∧ k=172 → b64k=b64[172] ∧ k=173 → b64k=b64[173] ∧ k=174 → b64k=b64[174] ∧ k=175 → b64k=b64[175] ∧
k=176 → b64k=b64[176] ∧ k=177 → b64k=b64[177] ∧ k=178 → b64k=b64[178] ∧ k=179 → b64k=b64[179] ∧ k=180 → b64k=b64[180] ∧ k=181 → b64k=b64[181] ∧ k=182 → b64k=b64[182] ∧
k=183 → b64k=b64[183] ∧ k=184 → b64k=b64[184] ∧ k=185 → b64k=b64[185] ∧ k=186 → b64k=b64[186] ∧ k=187 → b64k=b64[187] ∧ k=188 → b64k=b64[188] ∧ k=189 → b64k=b64[189] ∧
k=190 → b64k=b64[190] ∧ k=191 → b64k=b64[191] ∧ k=192 → b64k=b64[192] ∧ k=193 → b64k=b64[193] ∧ k=194 → b64k=b64[194] ∧ k=195 → b64k=b64[195] ∧ k=196 → b64k=b64[196] ∧
k=197 → b64k=b64[197] ∧ k=198 → b64k=b64[198] ∧ k=199 → b64k=b64[199] ∧ k=200 → b64k=b64[200] ∧ k=201 → b64k=b64[201] ∧ k=202 → b64k=b64[202] ∧ k=203 → b64k=b64[203] ∧
k=204 → b64k=b64[204] ∧ k=205 → b64k=b64[205] ∧ k=206 → b64k=b64[206] ∧ k=207 → b64k=b64[207] ∧ k=208 → b64k=b64[208] ∧ k=209 → b64k=b64[209] ∧ k=210 → b64k=b64[210] ∧
k=211 → b64k=b64[211] ∧ k=212 → b64k=b64[212] ∧ k=213 → b64k=b64[213] ∧ k=214 → b64k=b64[214] ∧ k=215 → b64k=b64[215] ∧ k=216 → b64k=b64[216] ∧ k=217 → b64k=b64[217] ∧
k=218 → b64k=b64[218] ∧ k=219 → b64k=b64[219] ∧ k=220 → b64k=b64[220] ∧ k=221 → b64k=b64[221] ∧ k=222 → b64k=b64[222] ∧ k=223 → b64k=b64[223] ∧ k=224 → b64k=b64[224] ∧
k=225 → b64k=b64[225] ∧ k=226 → b64k=b64[226] ∧ k=227 → b64k=b64[227] ∧ k=228 → b64k=b64[228] ∧ k=229 → b64k=b64[229] ∧ k=230 → b64k=b64[230] ∧ k=231 → b64k=b64[231] ∧
k=232 → b64k=b64[232] ∧ k=233 → b64k=b64[233] ∧ k=234 → b64k=b64[234] ∧ k=235 → b64k=b64[235] ∧ k=236 → b64k=b64[236] ∧ k=237 → b64k=b64[237] ∧ k=238 → b64k=b64[238] ∧
k=239 → b64k=b64[239] ∧ k=240 → b64k=b64[240] ∧ k=241 → b64k=b64[241] ∧ k=242 → b64k=b64[242] ∧ k=243 → b64k=b64[243] ∧ k=244 → b64k=b64[244] ∧ k=245 → b64k=b64[245] ∧
k=246 → b64k=b64[246] ∧ k=247 → b64k=b64[247] ∧ k=248 → b64k=b64[248] ∧ k=249 → b64k=b64[249] ∧ k=250 → b64k=b64[250] ∧ k=251 → b64k=b64[251] ∧ k=252 → b64k=b64[252] ∧
k=253 → b64k=b64[253] ∧ k=254 → b64k=b64[254] ∧ k=255 → b64k=b64[255]

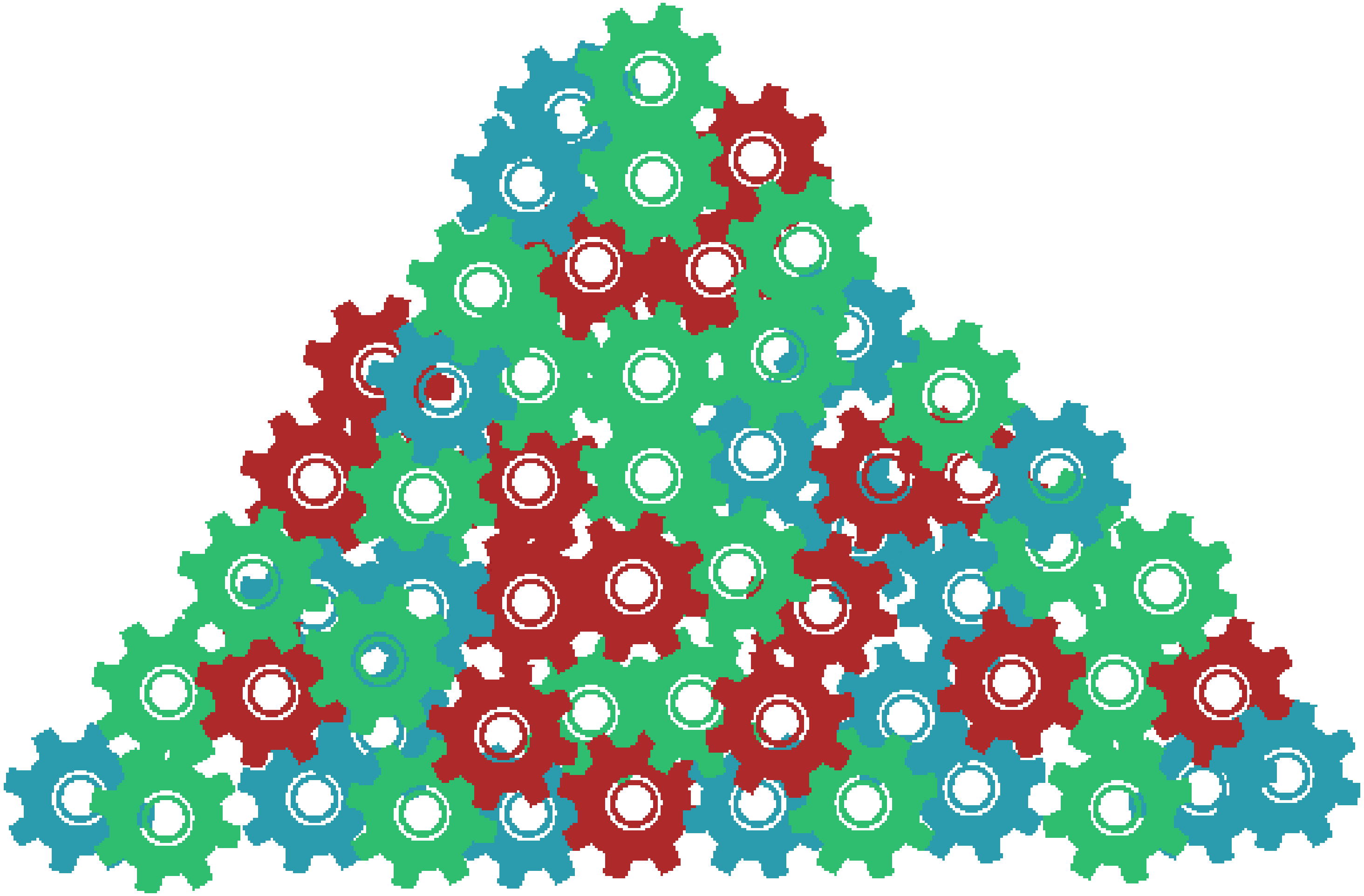
b64[0]=-1 ∧ b64[1]=-1 ∧ b64[2]=-1 ∧ b64[3]=-1 ∧ b64[4]=-1 ∧ b64[5]=-1 ∧ b64[6]=-1 ∧ b64[7]=-1 ∧ b64[8]=-1 ∧ b64[9]=-1 ∧ b64[10]=-1 ∧ b64[11]=-1 ∧ b64[12]=-1 ∧ b64[13]=-1 ∧ b64[14]=-1 ∧ b64[15]=-1
∧ b64[16]=-1 ∧ b64[17]=-1 ∧ b64[18]=-1 ∧ b64[19]=-1 ∧ b64[20]=-1 ∧ b64[21]=-1 ∧ b64[22]=-1 ∧ b64[23]=-1 ∧ b64[24]=-1 ∧ b64[25]=-1 ∧ b64[26]=-1 ∧ b64[27]=-1 ∧ b64[28]=-1 ∧ b64[29]=-1 ∧ b64[30]=-1
∧ b64[31]=-1 ∧ b64[32]=-1 ∧ b64[33]=-1 ∧ b64[34]=-1 ∧ b64[35]=-1 ∧ b64[36]=-1 ∧ b64[37]=-1 ∧ b64[38]=-1 ∧ b64[39]=-1 ∧ b64[40]=-1 ∧ b64[41]=-1 ∧ b64[42]=-1 ∧ b64[43]=62 ∧ b64[44]=-1 ∧ b64[45]=-1
∧ b64[46]=-1 ∧ b64[47]=63 ∧ b64[48]=52 ∧ b64[49]=53 ∧ b64[50]=54 ∧ b64[51]=55 ∧ b64[52]=56 ∧ b64[53]=57 ∧ b64[54]=58 ∧ b64[55]=59 ∧ b64[56]=60 ∧ b64[57]=61 ∧ b64[58]=-1 ∧ b64[59]=-1 ∧
b64[60]=-1 ∧ b64[61]=-1 ∧ b64[62]=-1 ∧ b64[63]=-1 ∧ b64[64]=-1 ∧ b64[65]=0 ∧ b64[66]=1 ∧ b64[67]=2 ∧ b64[68]=3 ∧ b64[69]=4 ∧ b64[70]=5 ∧ b64[71]=6 ∧ b64[72]=7 ∧ b64[73]=8 ∧ b64[74]=9 ∧
b64[75]=10 ∧ b64[76]=11 ∧ b64[77]=12 ∧ b64[78]=13 ∧ b64[79]=14 ∧ b64[80]=15 ∧ b64[81]=16 ∧ b64[82]=17 ∧ b64[83]=18 ∧ b64[84]=19 ∧ b64[85]=20 ∧ b64[86]=21 ∧ b64[87]=22 ∧ b64[88]=23 ∧
b64[89]=24 ∧ b64[90]=25 ∧ b64[91]=-1 ∧ b64[92]=-1 ∧ b64[93]=-1 ∧ b64[94]=-1 ∧ b64[95]=-1 ∧ b64[96]=-1 ∧ b64[97]=26 ∧ b64[98]=27 ∧ b64[99]=28 ∧ b64[100]=29 ∧ b64[101]=30 ∧ b64[102]=31 ∧
b64[103]=32 ∧ b64[104]=33 ∧ b64[105]=34 ∧ b64[106]=35 ∧ b64[107]=36 ∧ b64[108]=37 ∧ b64[109]=38 ∧ b64[110]=39 ∧ b64[111]=40 ∧ b64[112]=41 ∧ b64[113]=42 ∧ b64[114]=43 ∧ b64[115]=44 ∧
b64[116]=45 ∧ b64[117]=46 ∧ b64[118]=47 ∧ b64[119]=48 ∧ b64[120]=49 ∧ b64[121]=50 ∧ b64[122]=51 ∧ b64[123]=-1 ∧ b64[124]=-1 ∧ b64[125]=-1 ∧ b64[126]=-1 ∧ b64[127]=-1 ∧ b64[128]=-1 ∧
b64[129]=-1 ∧ b64[130]=-1 ∧ b64[131]=-1 ∧ b64[132]=-1 ∧ b64[133]=-1 ∧ b64[134]=-1 ∧ b64[135]=-1 ∧ b64[136]=-1 ∧ b64[137]=-1 ∧ b64[138]=-1 ∧ b64[139]=-1 ∧ b64[140]=-1 ∧ b64[141]=-1 ∧ b64[142]=-
1 ∧ b64[143]=-1 ∧ b64[144]=-1 ∧ b64[145]=-1 ∧ b64[146]=-1 ∧ b64[147]=-1 ∧ b64[148]=-1 ∧ b64[149]=-1 ∧ b64[150]=-1 ∧ b64[151]=-1 ∧ b64[152]=-1 ∧ b64[153]=-1 ∧ b64[154]=-1 ∧ b64[155]=-1 ∧
b64[156]=-1 ∧ b64[157]=-1 ∧ b64[158]=-1 ∧ b64[159]=-1 ∧ b64[160]=-1 ∧ b64[161]=-1 ∧ b64[162]=-1 ∧ b64[163]=-1 ∧ b64[164]=-1 ∧ b64[165]=-1 ∧ b64[166]=-1 ∧ b64[167]=-1 ∧ b64[168]=-1 ∧ b64[169]=-
1 ∧ b64[170]=-1 ∧ b64[171]=-1 ∧ b64[172]=-1 ∧ b64[173]=-1 ∧ b64[174]=-1 ∧ b64[175]=-1 ∧ b64[176]=-1 ∧ b64[177]=-1 ∧ b64[178]=-1 ∧ b64[179]=-1 ∧ b64[180]=-1 ∧ b64[181]=-1 ∧ b64[182]=-1 ∧
b64[183]=-1 ∧ b64[184]=-1 ∧ b64[185]=-1 ∧ b64[186]=-1 ∧ b64[187]=-1 ∧ b64[188]=-1 ∧ b64[189]=-1 ∧ b64[190]=-1 ∧ b64[191]=-1 ∧ b64[192]=-1 ∧ b64[193]=-1 ∧ b64[194]=-1 ∧ b64[195]=-1 ∧ b64[196]=-
1 ∧ b64[197]=-1 ∧ b64[198]=-1 ∧ b64[199]=-1 ∧ b64[200]=-1 ∧ b64[201]=-1 ∧ b64[202]=-1 ∧ b64[203]=-1 ∧ b64[204]=-1 ∧ b64[205]=-1 ∧ b64[206]=-1 ∧ b64[207]=-1 ∧ b64[208]=-1 ∧ b64[209]=-1 ∧
b64[210]=-1 ∧ b64[211]=-1 ∧ b64[212]=-1 ∧ b64[213]=-1 ∧ b64[214]=-1 ∧ b64[215]=-1 ∧ b64[216]=-1 ∧ b64[217]=-1 ∧ b64[218]=-1 ∧ b64[219]=-1 ∧ b64[220]=-1 ∧ b64[221]=-1 ∧ b64[222]=-1 ∧ b64[223]=-
1 ∧ b64[224]=-1 ∧ b64[225]=-1 ∧ b64[226]=-1 ∧ b64[227]=-1 ∧ b64[228]=-1 ∧ b64[229]=-1 ∧ b64[230]=-1 ∧ b64[231]=-1 ∧ b64[232]=-1 ∧ b64[233]=-1 ∧ b64[234]=-1 ∧ b64[235]=-1 ∧ b64[236]=-1 ∧
b64[237]=-1 ∧ b64[238]=-1 ∧ b64[239]=-1 ∧ b64[240]=-1 ∧ b64[241]=-1 ∧ b64[242]=-1 ∧ b64[243]=-1 ∧ b64[244]=-1 ∧ b64[245]=-1 ∧ b64[246]=-1 ∧ b64[247]=-1 ∧ b64[248]=-1 ∧ b64[249]=-1 ∧ b64[250]=-
1 ∧ b64[251]=-1 ∧ b64[252]=-1 ∧ b64[253]=-1 ∧ b64[254]=-1 ∧ b64[255]=-1 ∧

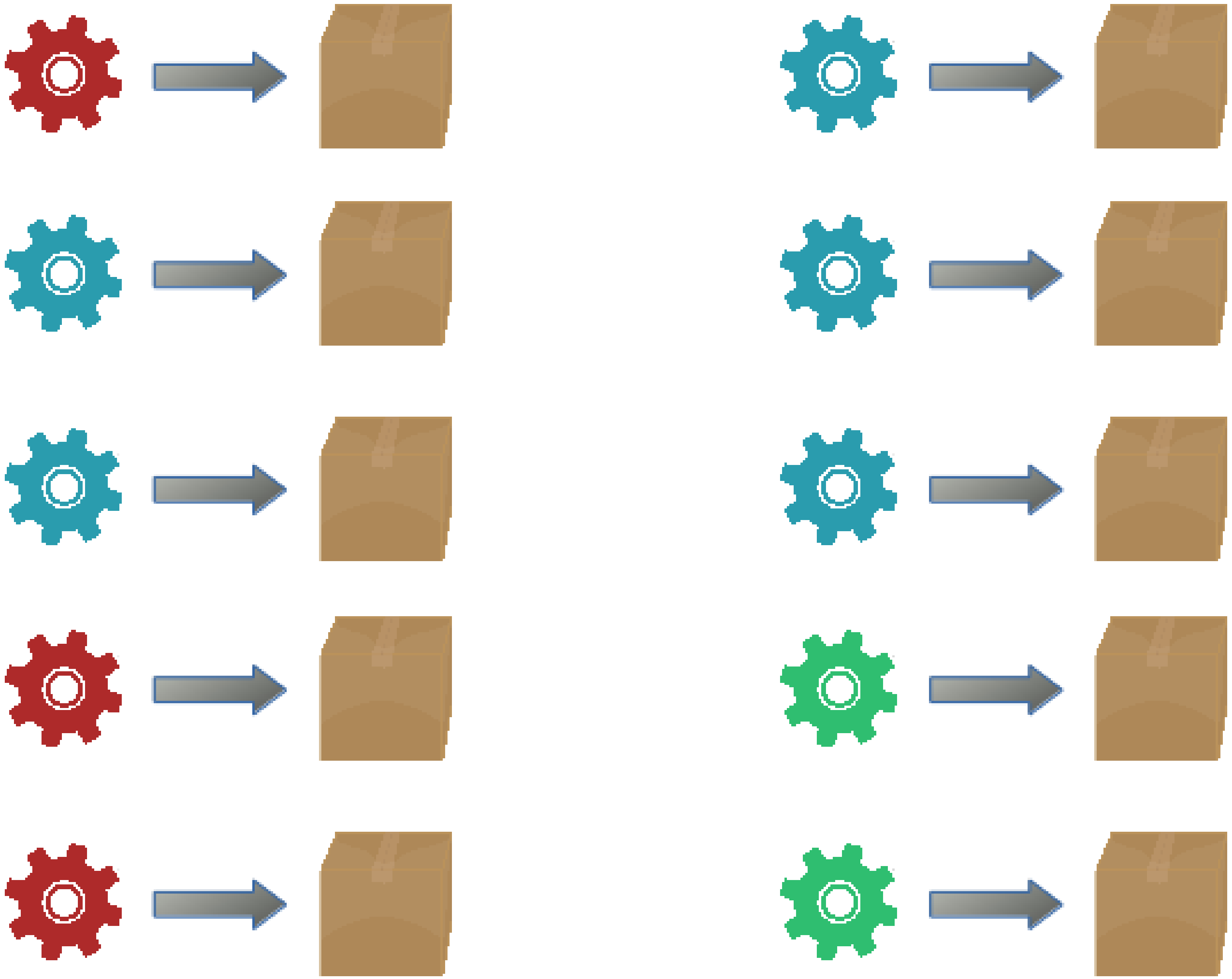
b64k ≥ 0 ∧

k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ k=2 → b64k=b64[2] ∧ k=3 → b64k=b64[3] ∧ k=4 → b64k=b64[4] ∧ k=5 → b64k=b64[5] ∧ k=6 → b64k=b64[6] ∧ k=7 → b64k=b64[7] ∧ k=8 → b64k=b64[8] ∧
k=9 → b64k=b64[9] ∧ k=10 → b64k=b64[10] ∧ k=11 → b64k=b64[11] ∧ k=12 → b64k=b64[12] ∧ k=13 → b64k=b64[13] ∧ k=14 → b64k=b64[14] ∧ k=15 → b64k=b64[15] ∧ k=16 → b64k=b64[16] ∧ k=17
→ b64k=b64[17] ∧ k=18 → b64k=b64[18] ∧ k=19 → b64k=b64[19] ∧ k=20 → b64k=b64[20] ∧ k=21 → b64k=b64[21] ∧ k=22 → b64k=b64[22] ∧ k=23 → b64k=b64[23] ∧ k=24 → b64k=b64[24] ∧ k=25 →
b64k=b64[25] ∧ k=26 → b64k=b64[26] ∧ k=27 → b64k=b64[27] ∧ k=28 → b64k=b64[28] ∧ k=29 → b64k=b64[29] ∧ k=30 → b64k=b64[30] ∧ k=31 → b64k=b64[31] ∧ k=32 → b64k=b64[32] ∧ k=33 →
b64k=b64[33] ∧ k=34 → b64k=b64[34] ∧ k=35 → b64k=b64[35] ∧ k=36 → b64k=b64[36] ∧ k=37 → b64k=b64[37] ∧ k=38 → b64k=b64[38] ∧ k=39 → b64k=b64[39] ∧ k=40 → b64k=b64[40] ∧ k=41 →
b64k=b64[41] ∧ k=42 → b64k=b64[42] ∧ k=43 → b64k=b64[43] ∧ k=44 → b64k=b64[44] ∧ k=45 → b64k=b64[45] ∧ k=46 → b64k=b64[46] ∧ k=47 → b64k=b64[47] ∧ k=48 → b64k=b64[48] ∧ k=49 →
b64k=b64[49] ∧ k=50 → b64k=b64[50] ∧ k=51 → b64k=b64[51] ∧ k=52 → b64k=b64[52] ∧ k=53 → b64k=b64[53] ∧ k=54 → b64k=b64[54] ∧ k=55 → b64k=b64[55] ∧ k=56 → b64k=b64[56] ∧ k=57 →
b64k=b64[57] ∧ k=58 → b64k=b64[58] ∧ k=59 → b64k=b64[59] ∧ k=60 → b64k=b64[60] ∧ k=61 → b64k=b64[61] ∧ k=62 → b64k=b64[62] ∧ k=63 → b64k=b64[63] ∧ k=64 → b64k=b64[64] ∧ k=65 →
b64k=b64[65] ∧ k=66 → b64k=b64[66] ∧ k=67 → b64k=b64[67] ∧ k=68 → b64k=b64[68] ∧ k=69 → b64k=b64[69] ∧ k=70 → b64k=b64[70] ∧ k=71 → b64k=b64[71] ∧ k=72 → b64k=b64[72] ∧ k=73 →
b64k=b64[73] ∧ k=74 → b64k=b64[74] ∧ k=75 → b64k=b64[75] ∧ k=76 → b64k=b64[76] ∧ k=77 → b64k=b64[77] ∧ k=78 → b64k=b64[78] ∧ k=79 → b64k=b64[79] ∧ k=80 → b64k=b64[80] ∧ k=81 →
b64k=b64[81] ∧ k=82 → b64k=b64[82] ∧ k=83 → b64k=b64[83] ∧ k=84 → b64k=b64[84] ∧ k=85 → b64k=b64[85] ∧ k=86 → b64k=b64[86] ∧ k=87 → b64k=b64[87] ∧ k=88 → b64k=b64[88] ∧ k=89 →
b64k=b64[89] ∧ k=90 → b64k=b64[90] ∧ k=91 → b64k=b64[91] ∧ k=92 → b64k=b64[92] ∧ k=93 → b64k=b64[93] ∧ k=94 → b64k=b64[94] ∧ k=95 → b64k=b64[95] ∧ k=96 → b64k=b64[96] ∧ k=97 →
b64k=b64[97] ∧ k=98 → b64k=b64[98] ∧ k=99 → b64k=b64[99] ∧ k=100 → b64k=b64[100] ∧ k=101 → b64k=b64[101] ∧ k=102 → b64k=b64[102] ∧ k=103 → b64k=b64[103] ∧ k=104 → b64k=b64[104] ∧
k=105 → b64k=b64[105] ∧ k=106 → b64k=b64[106] ∧ k=107 → b64k=b64[107] ∧ k=108 → b64k=b64[108] ∧ k=109 → b64k=b64[109] ∧ k=110 → b64k=b64[110] ∧ k=111 → b64k=b64[111] ∧ k=112 →
b64k=b64[112] ∧ k=113 → b64k=b64[113] ∧ k=114 → b64k=b64[114] ∧ k=115 → b64k=b64[115] ∧ k=116 → b64k=b64[116] ∧ k=117 → b64k=b64[117] ∧ k=118 → b64k=b64[118] ∧ k=119 →
b64k=b64[119] ∧ k=120 → b64k=b64[120] ∧ k=121 → b64k=b64[121] ∧ k=122 → b64k=b64[122] ∧ k=123 → b64k=b64[123] ∧ k=124 → b64k=b64[124] ∧ k=125 → b64k=b64[125] ∧ k=126 →
b64k=b64[126] ∧ k=127 → b64k=b64[127] ∧ k=128 → b64k=b64[128] ∧ k=129 → b64k=b64[129] ∧ k=130 → b64k=b64[130] ∧ k=131 → b64k=b64[131] ∧ k=132 → b64k=b64[132] ∧ k=133 →
b64k=b64[133] ∧ k=134 → b64k=b64[134] ∧ k=135 → b64k=b64[135] ∧ k=136 → b64k=b64[136] ∧ k=137 → b64k=b64[137] ∧ k=138 → b64k=b64[138] ∧ k=139 → b64k=b64[139] ∧ k=140 →
b64k=b64[140] ∧ k=141 → b64k=b64[141] ∧ k=142 → b64k=b64[142] ∧ k=143 → b64k=b64[143] ∧ k=144 → b64k=b64[144] ∧ k=145 → b64k=b64[145] ∧ k=146 → b64k=b64[146] ∧ k=147 →
b64k=b64[147] ∧ k=148 → b64k=b64[148] ∧ k=149 → b64k=b64[149] ∧ k=150 → b64k=b64[150] ∧ k=151 → b64k=b64[151] ∧ k=152 → b64k=b64[152] ∧ k=153 → b64k=b64[153] ∧ k=154 →
b64k=b64[154] ∧ k=155 → b64k=b64[155] ∧ k=156 → b64k=b64[156] ∧ k=157 → b64k=b64[157] ∧ k=158 → b64k=b64[158] ∧ k=159 → b64k=b64[159] ∧ k=160 → b64k=b64[160] ∧ k=161 →
b64k=b64[161] ∧ k=162 → b64k=b64[162] ∧ k=163 → b64k=b64[163] ∧ k=164 → b64k=b64[164] ∧ k=165 → b64k=b64[165] ∧ k=166 → b64k=b64[166] ∧ k=167 → b64k=b64[167] ∧ k=168 →
b64k=b64[168] ∧ k=169 → b64k=b64[169] ∧ k=170 → b64k=b64[170] ∧ k=171 → b64k=b64[171] ∧ k=172 → b64k=b64[172] ∧ k=173 → b64k=b64[173] ∧ k=174 → b64k=b64[174] ∧ k=175 →
b64k=b64[175] ∧ k=176 → b64k=b64[176] ∧ k=177 → b64k=b64[177] ∧ k=178 → b64k=b64[178] ∧ k=179 → b64k=b64[179] ∧ k=180 → b64k=b64[180] ∧ k=181 → b64k=b64[181] ∧ k=182 →
b64k=b64[182] ∧ k=183 → b64k=b64[183] ∧ k=184 → b64k=b64[184] ∧ k=185 → b64k=b64[185] ∧ k=186 → b64k=b64[186] ∧ k=187 → b64k=b64[187] ∧ k=188 → b64k=b64[188] ∧ k=189 →
b64k=b64[189] ∧ k=190 → b64k=b64[190] ∧ k=191 → b64k=b64[191] ∧ k=192 → b64k=b64[192] ∧ k=193 → b64k=b64[193] ∧ k=194 → b64k=b64[194] ∧ k=195 → b64k=b64[195] ∧ k=196 →
b64k=b64[196] ∧ k=197 → b64k=b64[197] ∧ k=198 → b64k=b64[198] ∧ k=199 → b64k=b64[199] ∧ k=200 → b64k=b64[200] ∧ k=201 → b64k=b64[201] ∧ k=202 → b64k=b64[202] ∧ k=203 →
b64k=b64[203] ∧ k=204 → b64k=b64[204] ∧ k=205 → b64k=b64[205] ∧ k=206 → b64k=b64[206] ∧ k=207 → b64k=b64[207] ∧ k=208 → b64k=b64[208] ∧ k=209 → b64k=b64[209] ∧ k=210 →
b64k=b64[210] ∧ k=211 → b64k=b64[211] ∧ k=212 → b64k=b64[212] ∧ k=213 → b64k=b64[213] ∧ k=214 → b64k=b64[214] ∧ k=215 → b64k=b64[215] ∧ k=216 → b64k=b64[216] ∧ k=217 →
b64k=b64[217] ∧ k=218 → b64k=b64[218] ∧ k=219 → b64k=b64[219] ∧ k=220 → b64k=b64[220] ∧ k=221 → b64k=b64[221] ∧ k=222 → b64k=b64[222] ∧ k=223 → b64k=b64[223] ∧ k=224 →
b64k=b64[224] ∧ k=225 → b64k=b64[225] ∧ k=226 → b64k=b64[226] ∧ k=227 → b64k=b64[227] ∧ k=228 → b64k=b64[228] ∧ k=229 → b64k=b64[229] ∧ k=230 → b64k=b64[230] ∧ k=231 →
b64k=b64[231] ∧ k=232 → b64k=b64[232] ∧ k=233 → b64k=b64[233] ∧ k=234 → b64k=b64[234] ∧ k=235 → b64k=b64[235] ∧ k=236 → b64k=b64[236] ∧ k=237 → b64k=b64[237] ∧ k=238 →
b64k=b64[238] ∧ k=239 → b64k=b64[239] ∧ k=240 → b64k=b64[240] ∧ k=241 → b64k=b64[241] ∧ k=242 → b64k=b64[242] ∧ k=243 → b64k=b64[243] ∧ k=244 → b64k=b64[244] ∧ k=245 →
b64k=b64[245] ∧ k=246 → b64k=b64[246] ∧ k=247 → b64k=b64[247] ∧ k=248 → b64k=b64[248] ∧ k=249 → b64k=b64[249] ∧ k=250 → b64k=b64[250] ∧ k=251 → b64k=b64[251] ∧ k=252 →
b64k=b64[252] ∧ k=253 → b64k=b64[253] ∧ k=254 → b64k=b64[254] ∧ k=255 → b64k=b64[255]

Impact on the Solver

- This explosion of variables creates an incredibly large search space
- Solver wastes time exploring multiple solutions with different indexes that point to the same array value
- Complicated queries make the performance even worse as backtracking results in more redundant exploration






FRAGILE

Our Technique

- Takes advantage of statically and dynamically available information about the target array
- Applies one of two optimizations depending on how the array read is used
- Yields a simplified query that results in dramatic performance improvement in programs that read from large arrays with symbolic indexes

Index-Based Transformation

- Only applicable to conditionals comparing array reads with statically known values
- Turns the comparison operation into a conjunctive formula that compares index ranges without the explicit array read
- Avoids the overhead of representing values in the array you don't need
- Creates the most concise encoding of either of our transformations

Index-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= 0)
        return 1;
    else return 0;
}		

Index-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= 0)
        return 1;
    else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= 0 ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 →
	b64k=b64[1] ∧ ...	

Index-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
if(k > 255)
return -1;
if(b64[k] >= 0)
return 1;
else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= 0 ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 →
	b64k=b64[1] ∧ ...
		k = 43 ∨

Index-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= 0)
        return 1;
    else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= 0 ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ ...
		k = 43 ∨
		
		47 <= k <= 57 ∨

Index-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

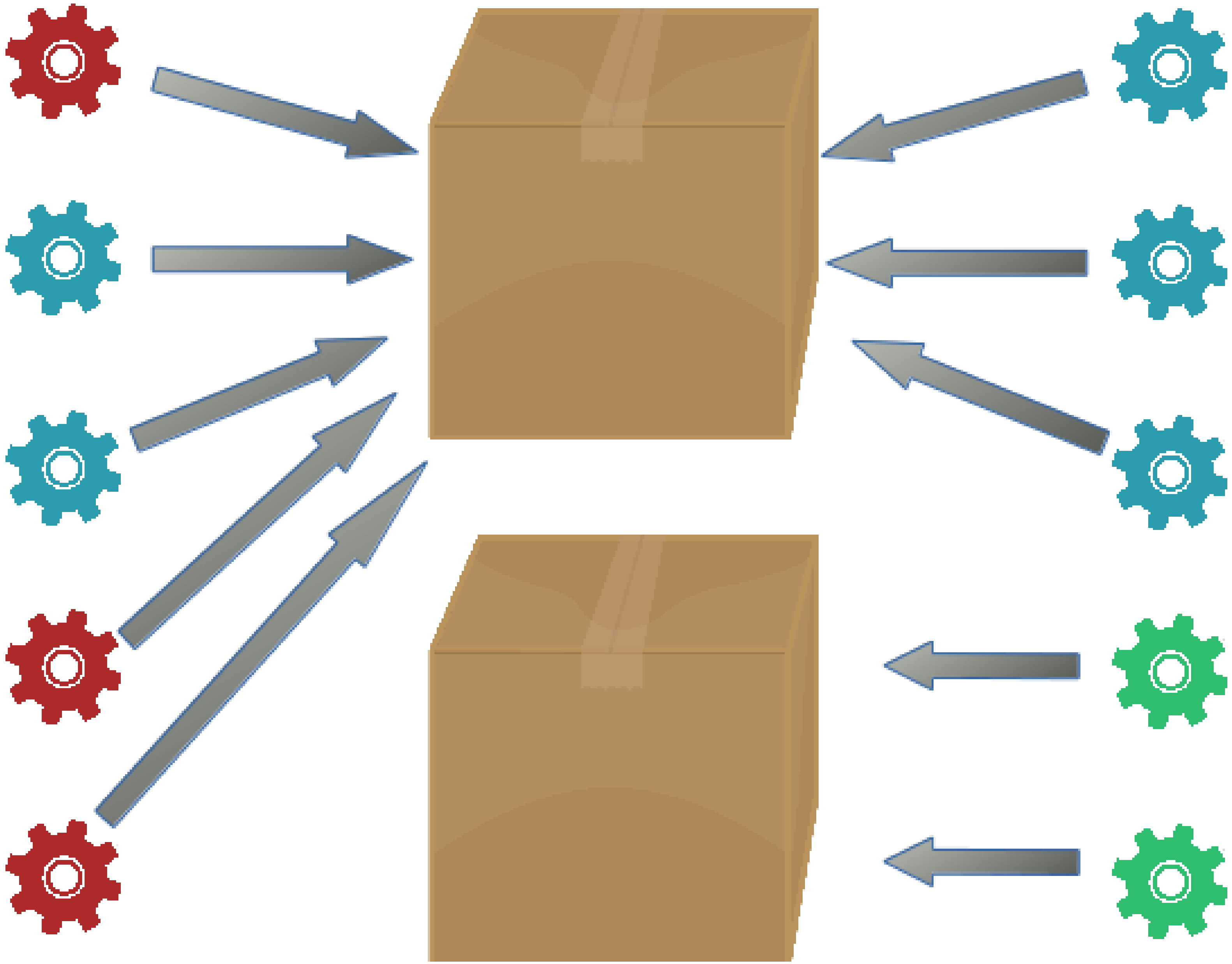
`isBase64(unsigned k) {`
`    if(k > 255)`
`        return -1;`
`    if(b64[k] >= 0)`
`        return 1;`
`    else return 0;`
`}`
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= 0 ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ ...
		$\boxed{k = 43 \lor}$
		$\boxed{47 <= k <= 57 \lor}$
		$\boxed{65 <= k <= 90}$

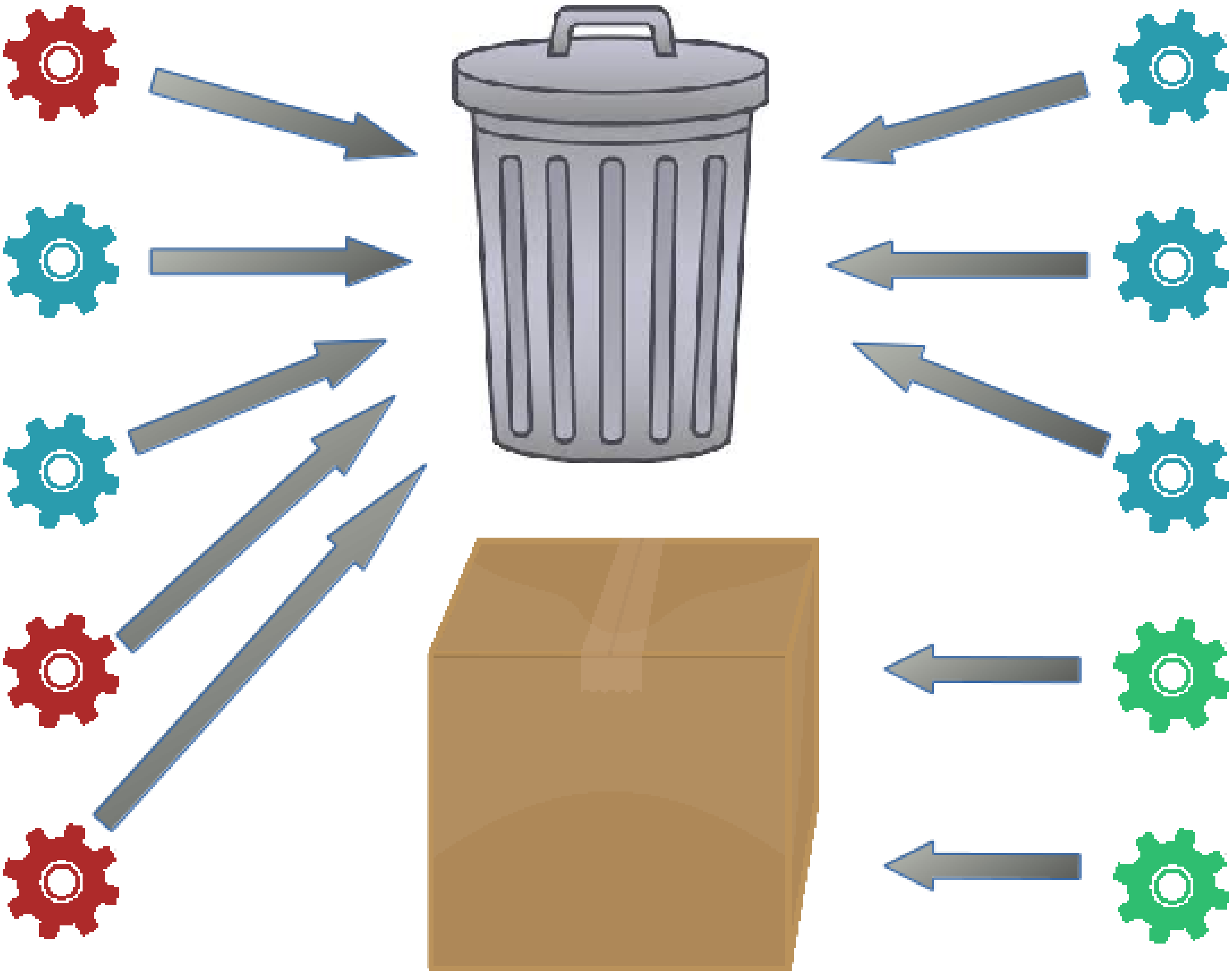
Index-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= 0)
        return 1;
    else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= 0 ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ ...
		k = 43 ∨
		47 <= k <= 57 ∨
		65 <= k <= 90
		97 <= k <= 122





Value-Based Transformation

- Applicable to all array reads
- Turns the array read into a series of nested ITE's comparing the index to a range of offsets that correspond to the same value
- Removes the redundancy created by the traditional Theory of Arrays

Value-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= sym)
        return 1;
    else return 0;
}		

Value-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= sym)
        return 1;
    else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 →
	b64k=b64[1] ∧ ...	

Value-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

`isBase64(unsigned k) {`
`    if(k > 255)`
`        return -1;`
`    if(b64[k] >= sym)`
`        return 1;`
`    else return 0;`
`}`
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ ...
		x = Ite(0≤k≤42| 44≤k≤46| …, -1,

Value-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
    if(k > 255)
        return -1;
    if(b64[k] >= sym)
        return 1;
    else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 →
	b64k=b64[1] ∧ ...
		x = Ite(0≤k≤42| 44≤k≤46|
		…. -1,
		
		ite(k == 43, 62,

Value-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

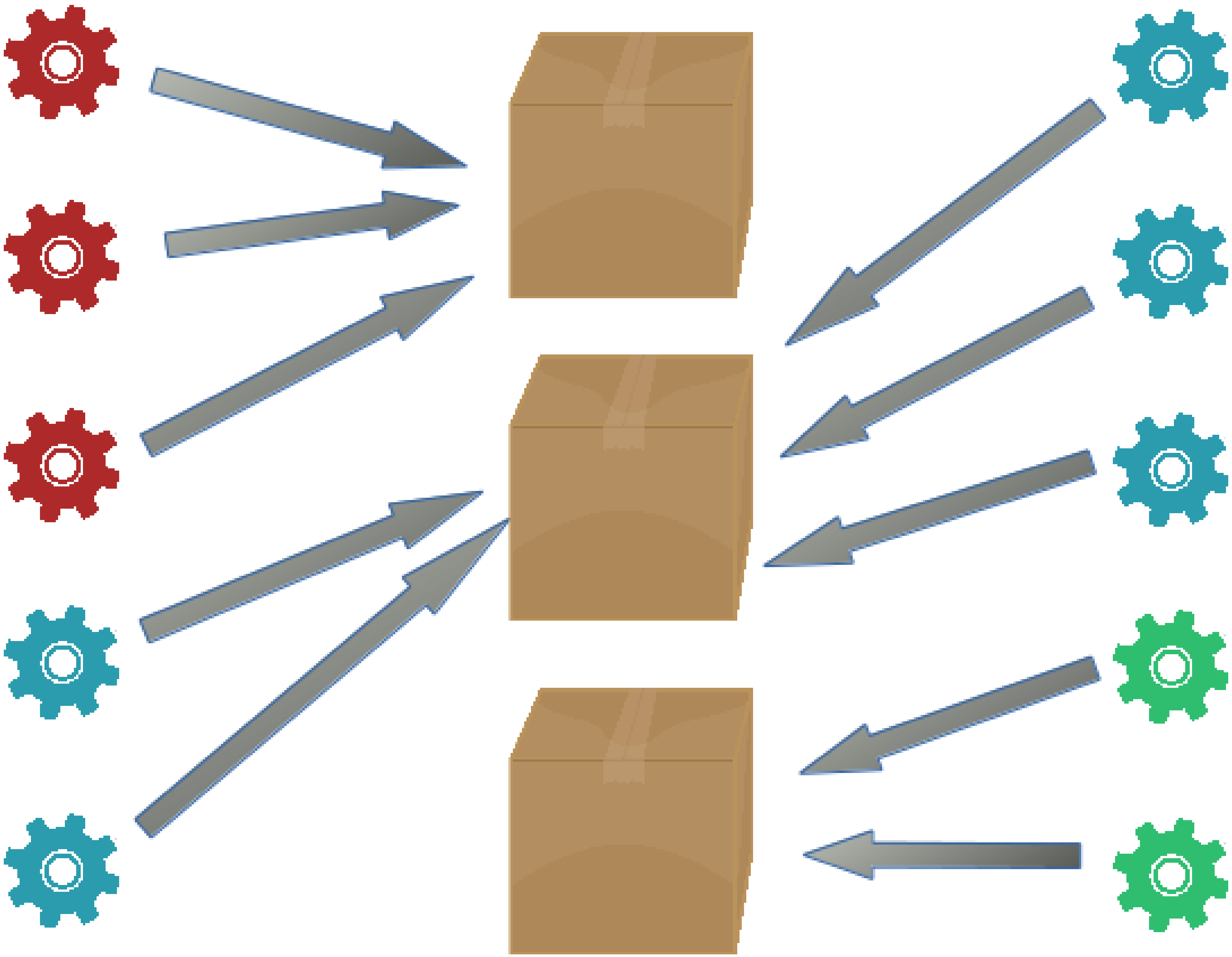
isBase64(unsigned k) {
if(k > 255)
return -1;
if(b64[k] >= sym)
return 1;
else return 0;
}
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ ...
		x = Ite(0≤k≤42| 44≤k≤46| …. -1,
		ite(k == 43, 62,
		ite(k==47, 63,

Value-Based Transformation

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

`isBase64(unsigned k) {`
`if(k > 255)`
`return -1;`
`if(b64[k] >= sym)`
`return 1;`
`else return 0;`
`}`
	// Array Variables
	b64[0]=-1 ∧ b64[1]=-1 ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 → b64k=b64[1] ∧ ...
		x = Ite(0≤k≤42| 44≤k≤46| …. -1,
		ite(k == 43, 62,
		ite(k==47, 63,
		x >= sym



What about partially symbolic arrays?

- Arrays can become partially symbolic due to program behavior or decisions made during analysis
- the Value-based transformation can be extended to handle them
- Add an individual case for each symbolic value in the array

Partially Symbolic Arrays

```
char b64[256] = { -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, 62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1,
-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
23, 24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37,
38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
b64[0] = sym0;
b64[1] = sym1;
b64[2] = sym2;
b64[3] = sym3;
if(b64[k] >= sym)
return 1;
else return 0;
}
	// Array Variables
	b64[0]= ? ∧ b64[1]= ? ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 →
	b64k=b64[1] ∧ ..	

Partially Symbolic Arrays

```
char b64[256] = { ? , ? , ? , ?, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1,-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
62, -1, -1, -1, 63, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, -1, -1, -1, -1, -1, -1, -1,
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23,
24, 25, -1, -1, -1, -1, -1, -1, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38,
39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1
};
```

Target Program	Original Constraints	Opt Constraints

isBase64(unsigned k) {
b64[0] = sym0;
b64[1] = sym1;
b64[2] = sym2;
b64[3] = sym3;
if(b64[k] >= sym)
return 1;
else return 0;
}
	// Array Variables
	b64[0]= ? ∧ b64[1]= ? ∧ … ∧
	//Array Conditional
	b64k >= sym ∧
	// Read Operation
	k=0 → b64k=b64[0] ∧ k=1 →
	b64k=b64[1] ∧ ..
		ite(k == 0,
		b64[0],
		ite(k==1,
		b64[1],
		ite(k==2,
		b64[2],
		...

How are the transformations implemented?

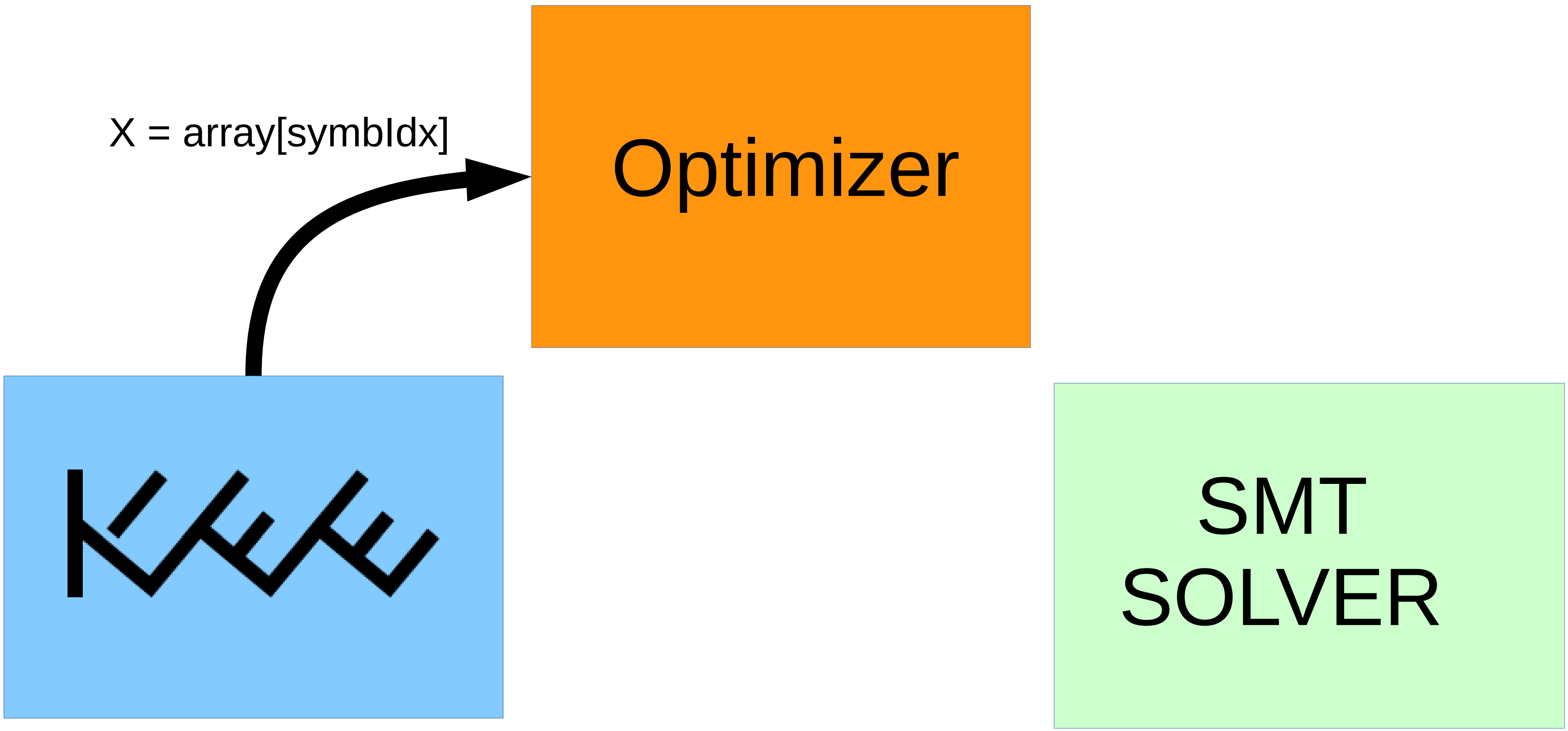
Optimizer

KLEE

SMT SOLVER

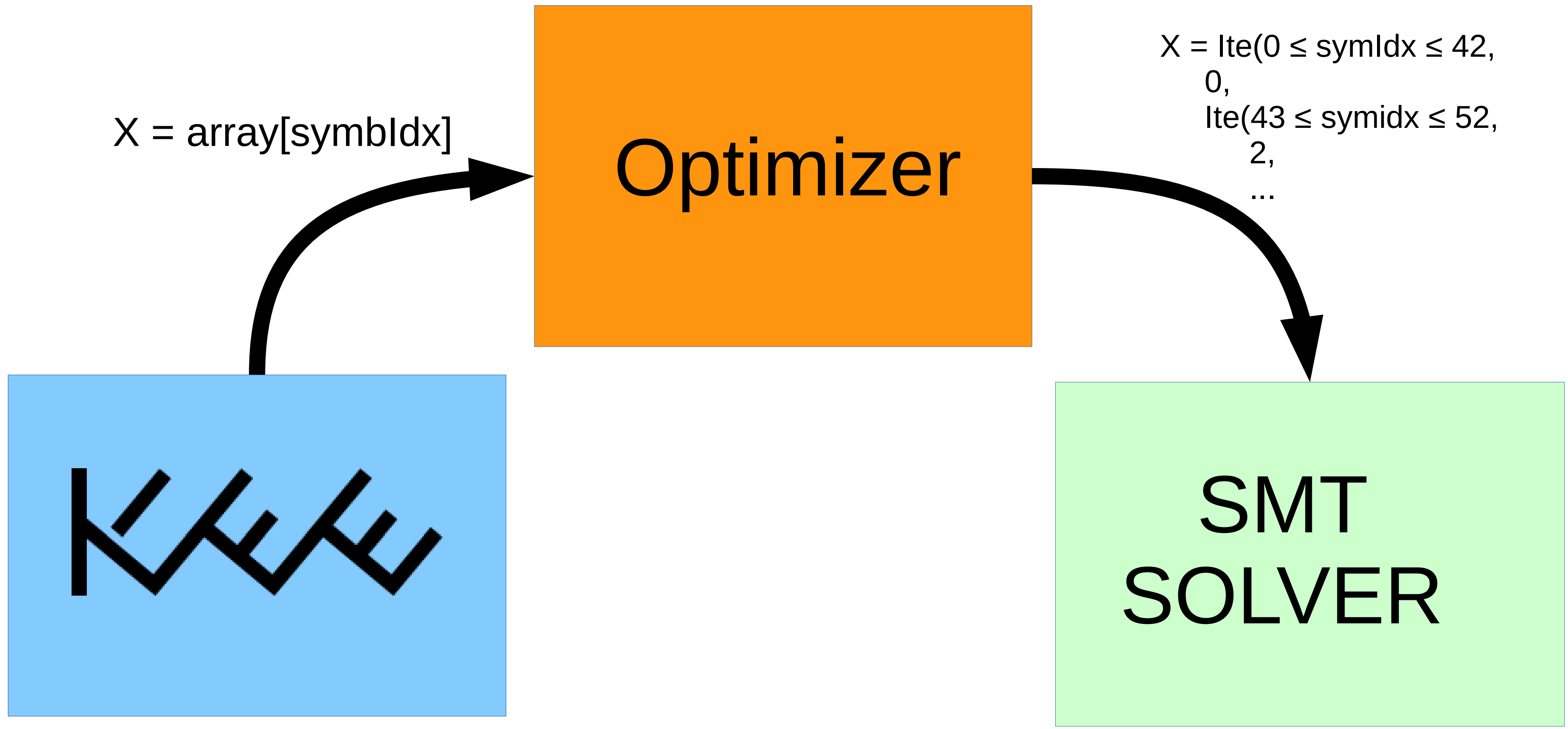
Implementation is available at: https://srg.doc.ic.ac.uk/projects/klee-array/artifact.html

How are the transformations implemented?



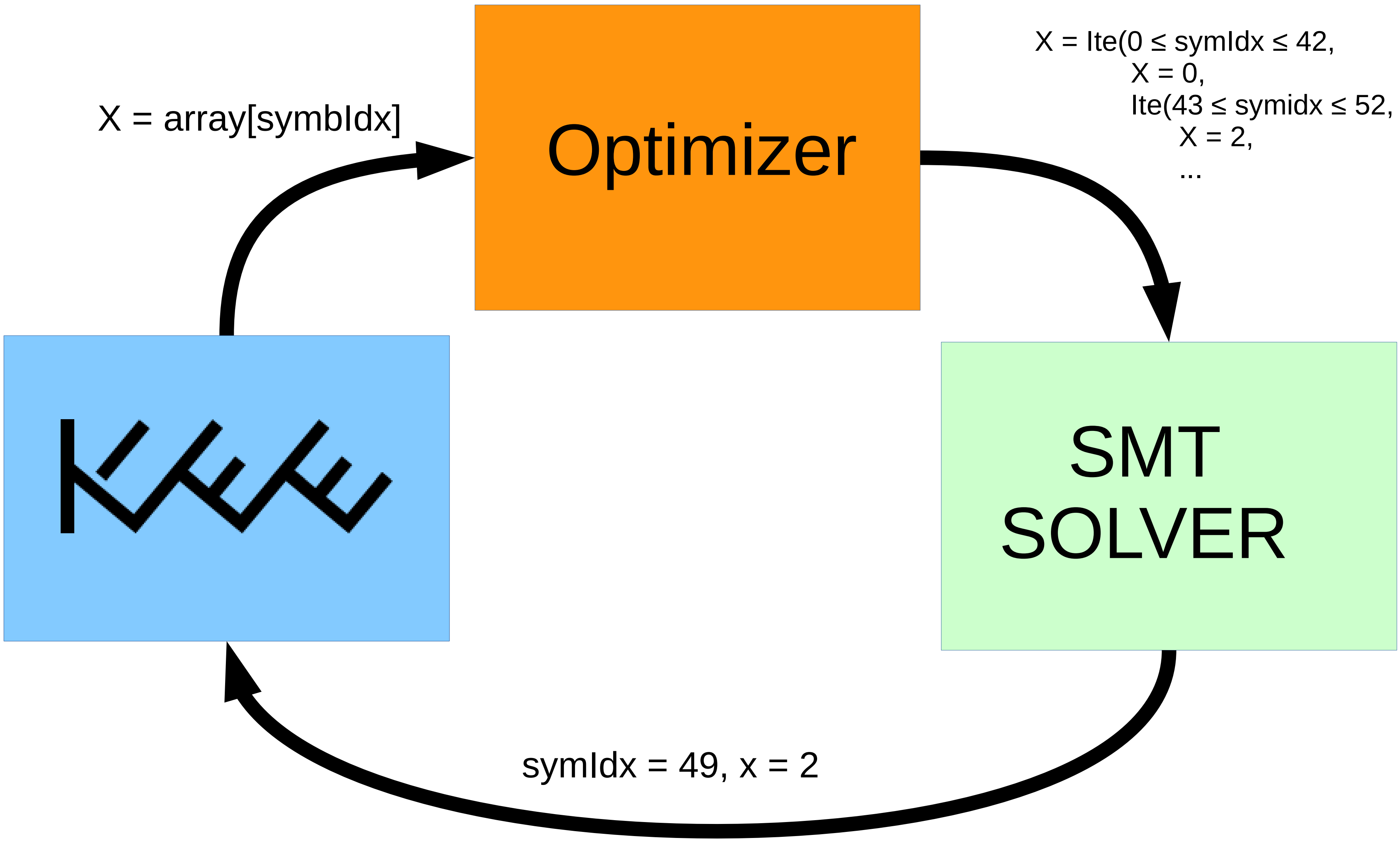
Implementation is available at: https://srg.doc.ic.ac.uk/projects/klee-array/artifact.html

How are the transformations implemented?



Implementation is available at: https://srg.doc.ic.ac.uk/projects/klee-array/artifact.html

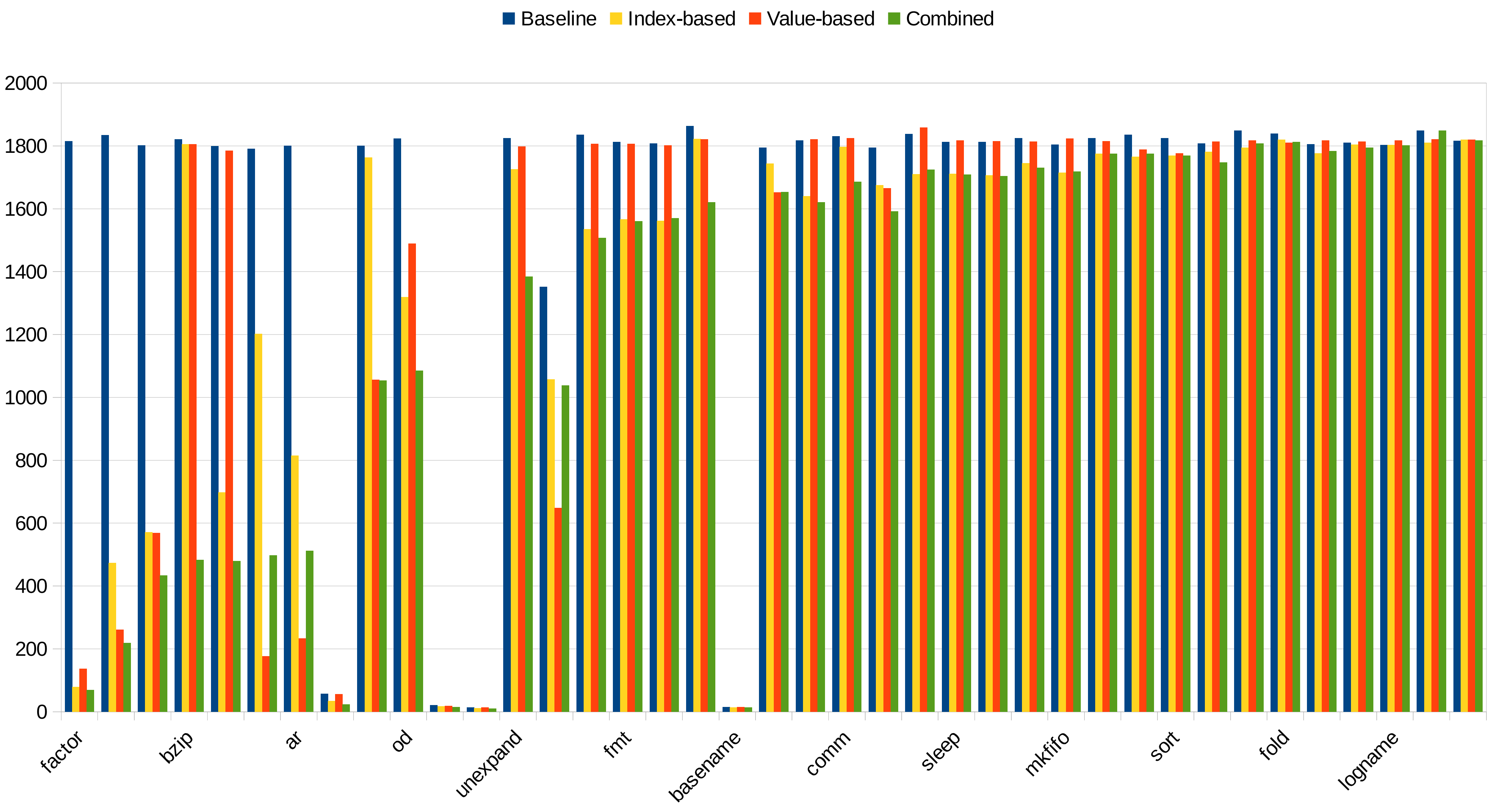
How are the transformations implemented?



Evaluation: Speed

- Performed on 104 programs from coreutils, binutils,and other open source repositories
- Baseline and Optimized runs execute the same number of instructions
- Instructions executed are logged to ensure fairness
- 7 programs with more than 3x speedup and none with slowdown

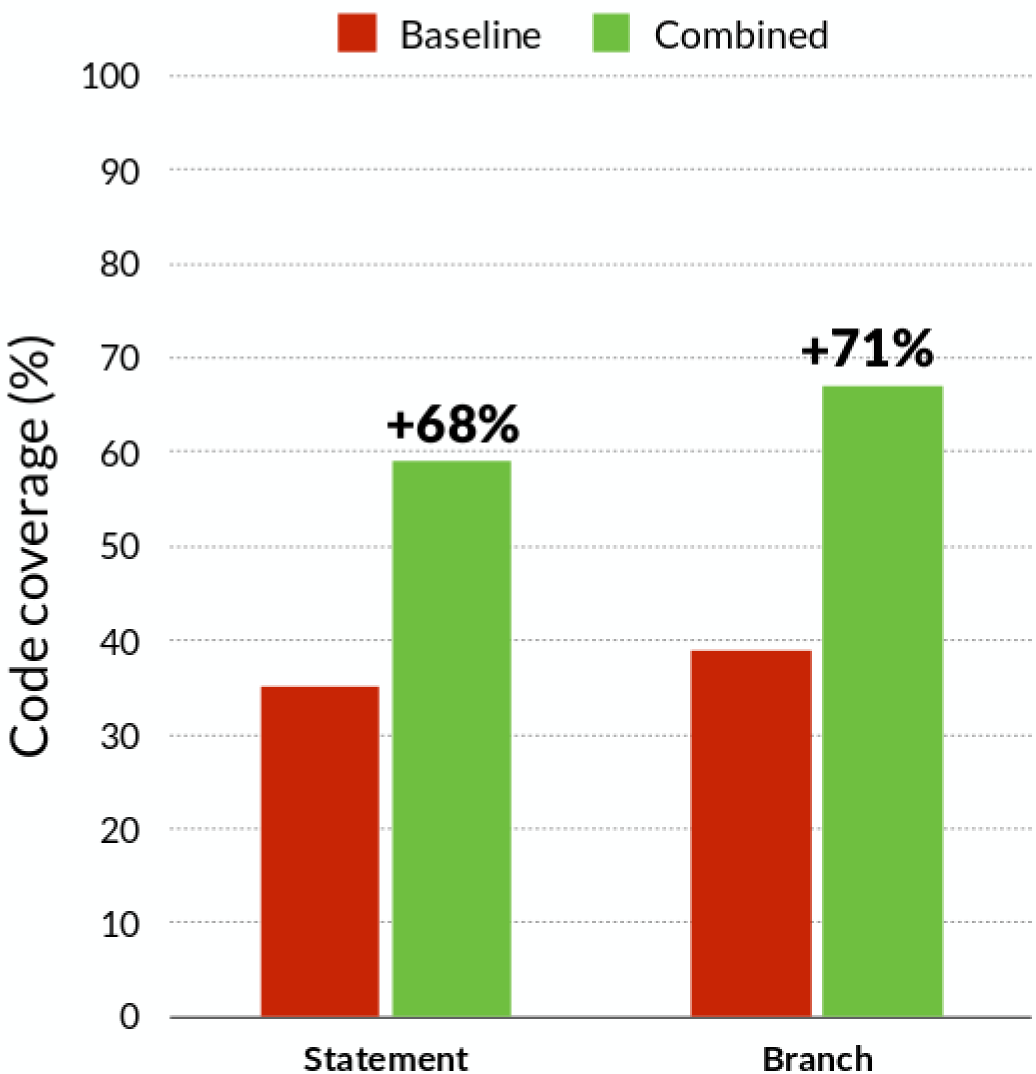
Evaluation: Speed



Evaluation: Code Coverage

- Performed on the program BC
- Baseline and optimized runs use a heuristic based search strategy designed to explore uncovered code
- Both programs are analyzed for 6 hours creating inputs with the most code coverage possible

Evaluation: Code Coverage



BC

Related Work

- Constraint Optimization
  - V. Ganesh and D. L. Dill. A decision procedure for bit-vectors and arrays. In Proc. of the 19th International Conference on Computer-Aided Veriication (CAV'07) July 2007.
  - Erete and A. Orso. Optimizing constraint solving to better support symbolic execution. In Proc. of the Workshop on Constraints in Software Testing, Verification, and Analysis (CSTVA'11), Mar. 2011.
  - S. Dong, O. Olivo, L. Zhang, and S. Khurshid. Studying the influence of standard compiler optimizations on symbolic execution. In Proc. of the 26th International Symposium on Software Reliability Engineering (ISSRE'15), Nov. 2015.

Conclusion

- Our technique uses static and dynamic information to build specific encodings for individual arrays
- This encoding strategy yields considerable improvement in SMT solver performance
- This speedup allows symbolic execution to explore more code at a faster rate

Q&A

Thank You!

David Perry
PhD Student, Purdue University

Contact: perry74@purdue.edu