Détermination de propriétés de flots de données pour l'amélioration du temps d'exécution pire-cas

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Introduction

Équipe TRACES

Plan

Estimation du pire temps d'exécution (WCET)

- But : surestimer le temps d'exécution d'une partie de programme
- Exemples
  - Le frein de voiture s'activera au pire 50ms après la commande
  - L'algorithme prendra une décision en moins d'1s
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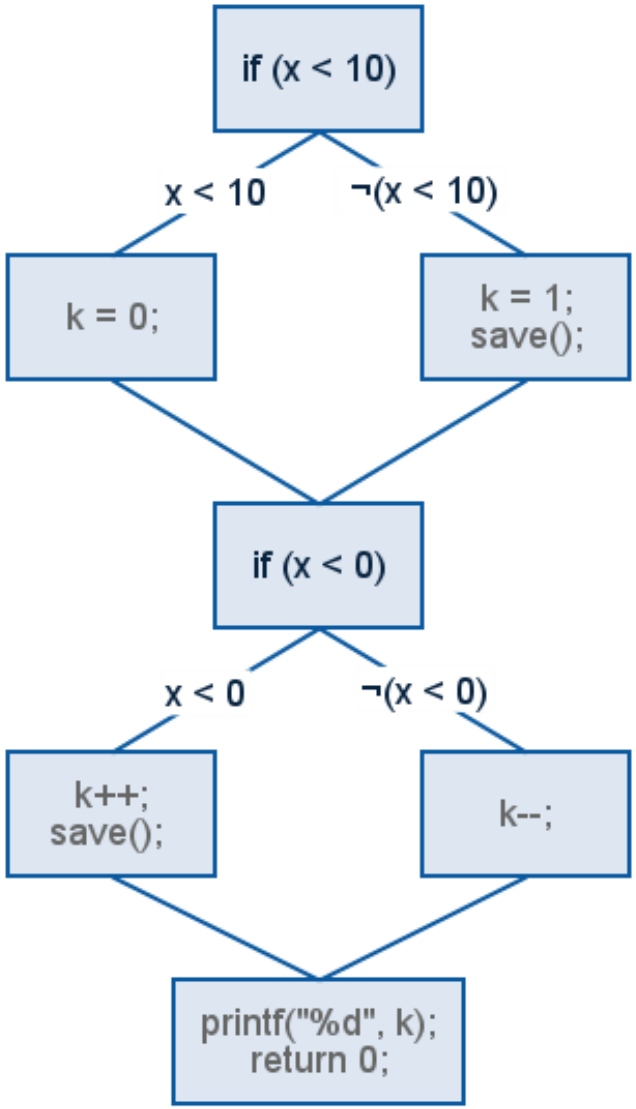
- Systèmes temps-réel critiques : les mesures ne suffisent pas, il faut une **preuve** !
- Calcul du pire-temps : maximisation en ILP
  - $WCET = \max \sum x_i \ t_i$
    $+$ contraintes matérielles $+$ contraintes logicielles

Recherche de chemins infaisables

- Graphe de flot de contrôle



Recherche de chemins infaisables

- Graphe de flot de contrôle
- Chemins + SMT
  - $(x < 10) \wedge (x < 0)$
  - $(x < 10) \wedge \neg(x < 0)$
  - $\neg(x < 10) \wedge (x < 0) \models \bot$
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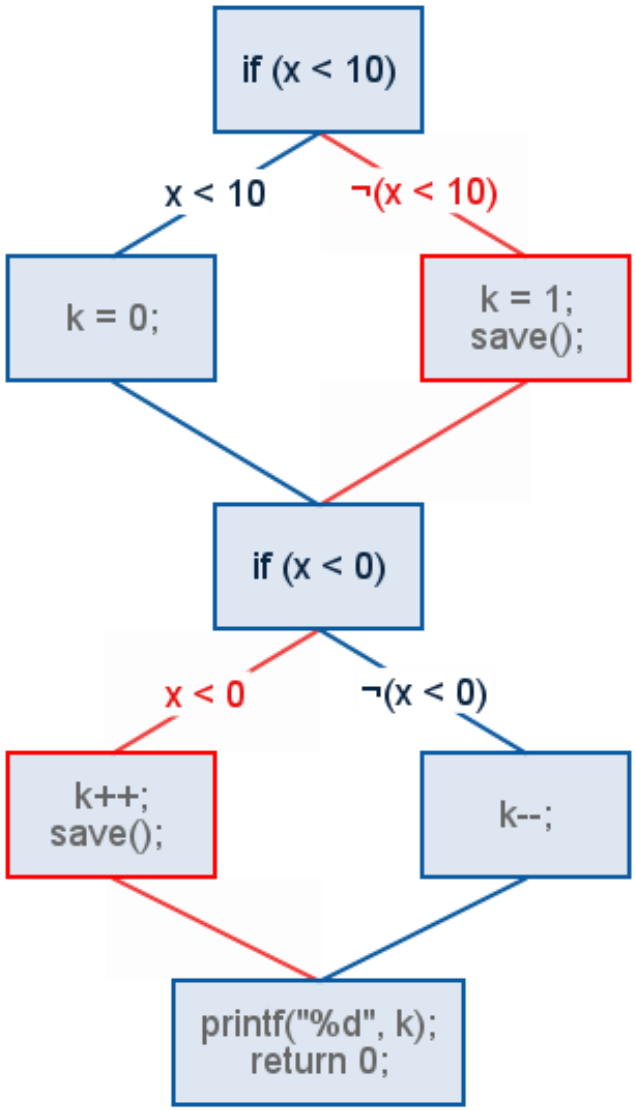

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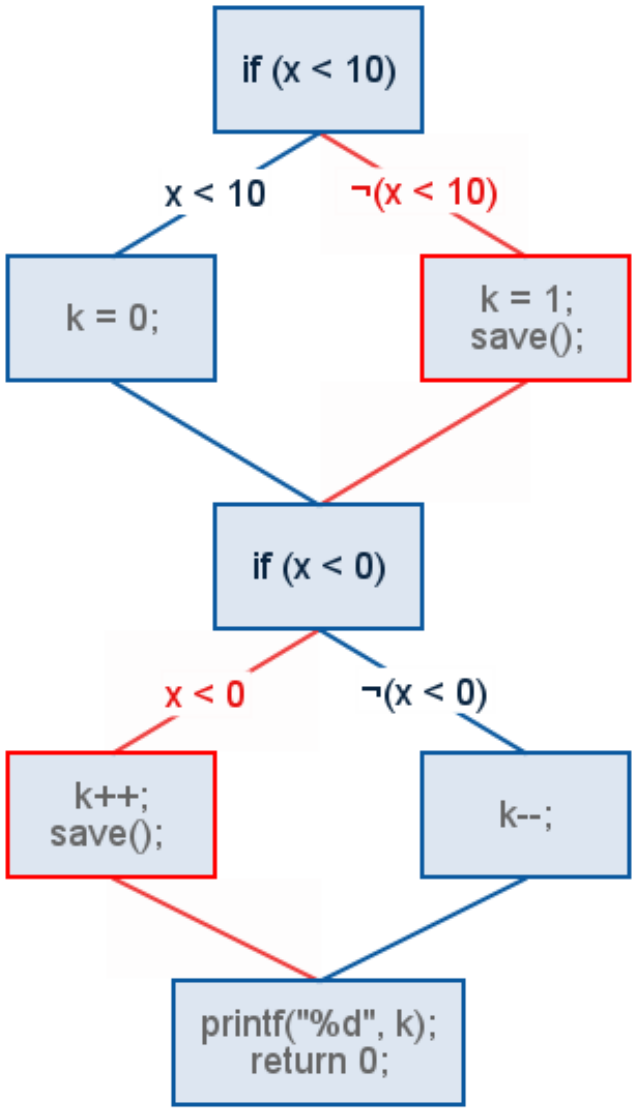
- Chemin infaisable

  $\Rightarrow$ contrainte ILP

  $n_{(x<0)} \leq n_{(x<10)}$

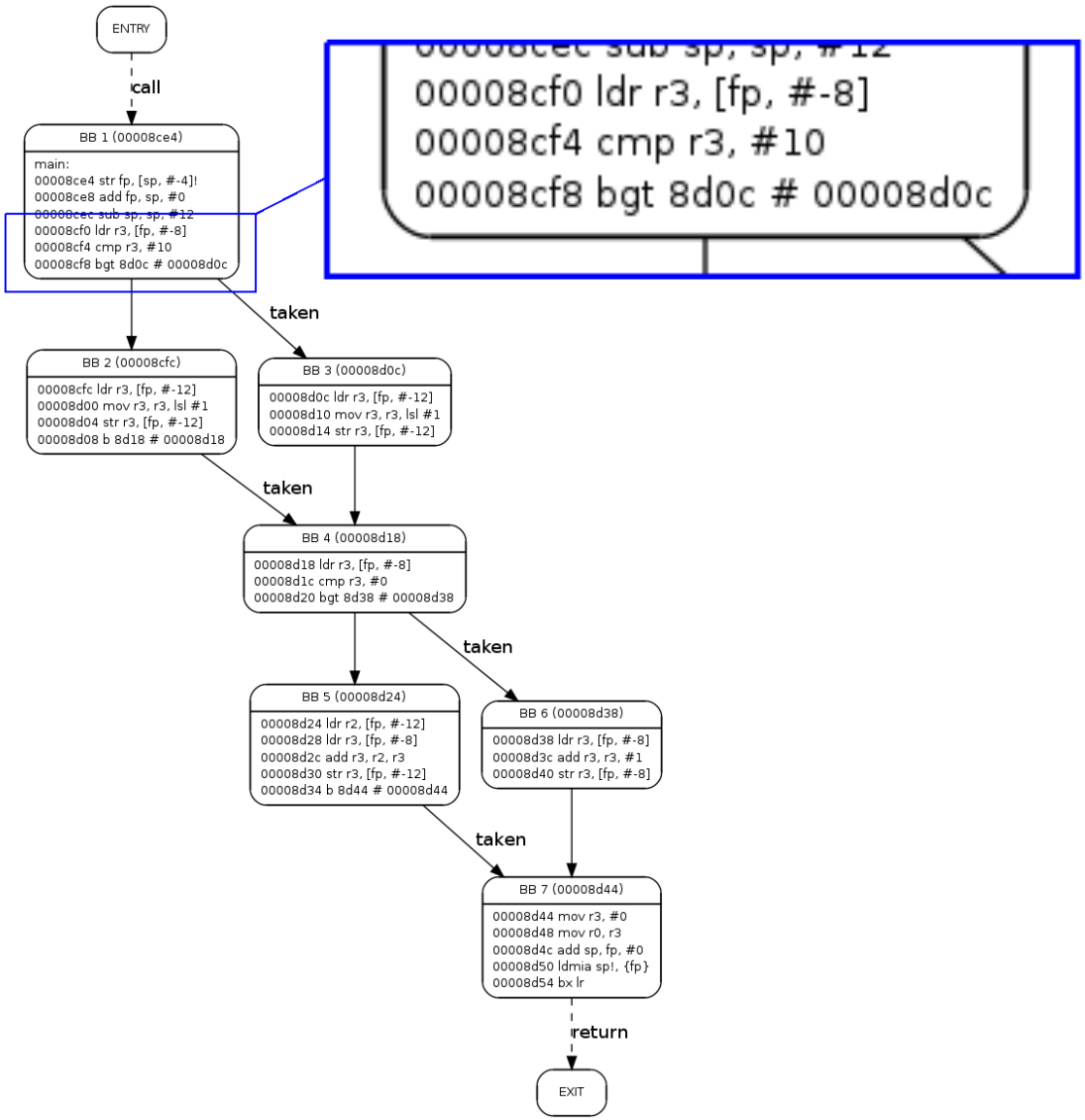


Choix du solveur SMT

Notre choix de solveur s'est porté sur **CVC4** :

- Open-source, licence très libre
- De très bons résultats à la SMT-COMP
- Une API C++ riche et bien documentée

Graphe en langage machine



Les instructions sémantiques d'OTAWA

```
ldr r0, [pc, #20]
@ seti ?15, 0x8310
@ seti t2, 0x14
@ add t1, ?15, t2
@ load ?0, t1, uint32

mov r1, #0
@ seti ?1, 0x0

mov r2, r1
@ set t1, ?1
@ set ?2, t1

bl 8574
@ seti t1, 0x8574
@ seti ?14, 0x8318
@ branch t1
```

Les variables d'OTAWA :

- les registres machine ?0, ?1...(16, 32... ou plus selon l'architecture)
- des variables temporaires t1, t2...
  - locales à une instruction machine (détruites à la fin)
  - aident à la traduction en instructions sémantiques

Les instructions sémantiques d'OTAWA

- Une trentaine d'instructions sémantiques
- On fait de l'analyse abstraite : on met à $\top$ quand on ne sait pas gérer

  $\Longrightarrow$ instruction `SCRATCH`

  $\Longrightarrow$ Il s'agit de toujours rester **correct**

Plan

Représentation des prédicats

- **Prédicat** : Expression $\times$ Comparateur $\times$ Expression
- **Expression** :
  - — Constante(k $\in \mathbb{Z}$)
  - — Variable(id $\in \mathbb{Z}$)
  - — Memoire(addr $\in \mathbb{Z}$)
  - — ExprArithmétique
- **ExprArithmétique** : Expression $\times$ Operateur $\times$ Expression

```
05]   + ?14 = [t1 - 4]
04]   - ?4 = [(t1 - t2) - t2]
05]   + ?4 = [(t1 - 4) - 4]
04]   - ?13 - ((t1 - t2) - t2) = 8
05]   + ?13 - ((t1 - 4) - 4) = 8
60] - t2 = 4
74] - ?14 = [t1 - 4]
74] - ?4 = [(t1 - 4) - 4]
74] - ?13 - ((t1 - 4) - 4) = 8
22] bx lr
30] branch ?14
03] Predicates generated: [?0 = 0]
02] Processing Edge: BB 10 (00008318) -> EXIT (virtual)
52] EXIT block reached
02] Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
06] SMT call: UNSAT
33] [Inf. path found: [1->3, 5->6] (bitcode=101)]
62] Current path identified as infeasible, stopping analysis
02] Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
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66] Processing BB 2 (000082e8)
22] bl 8278
30] seti t1, 0x8278 (33400)
38]   + t1 = 0x8278
30] seti ?14, 0x82ec (33516)
38]   + ?14 = 0x82ec
30] branch t1
60] - t1 = 0x8278
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66] Processing BB 4 (000082ec)
22] b 82f4
30] seti t1, 0x82f4 (33524)
38]   + t1 = 0x82f4
30] branch t1
60] - t1 = 0x82f4
```

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417]   - (?14 = 0x8318 | 9->10)
388]   + ?14 = [t1]
:30] add t1, t1, t2
516]   [t1 - t2 / t1]
545]     - ?14 = [t1]
553]     + ?14 = [t1 - t2]
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branch t1
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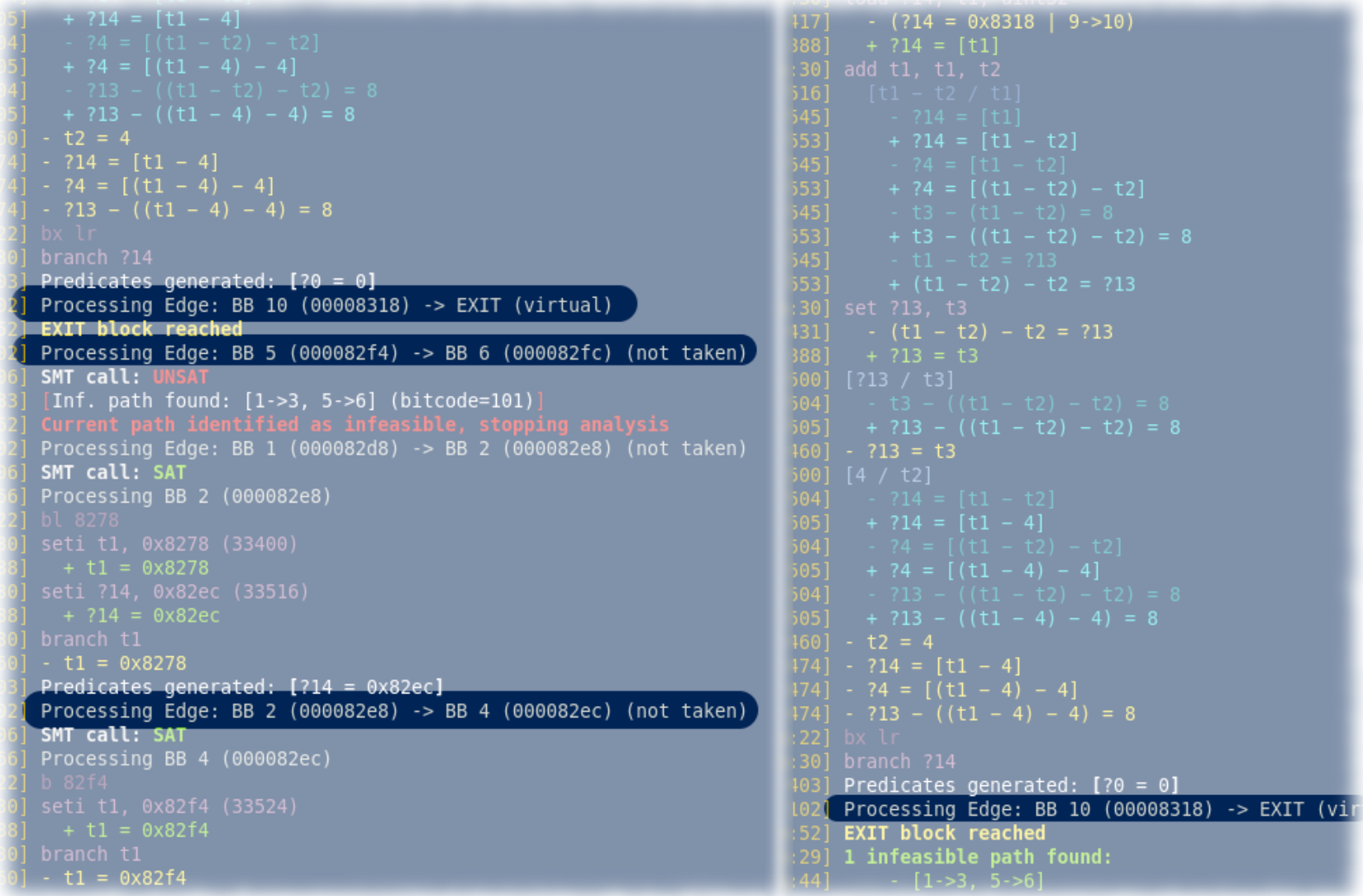
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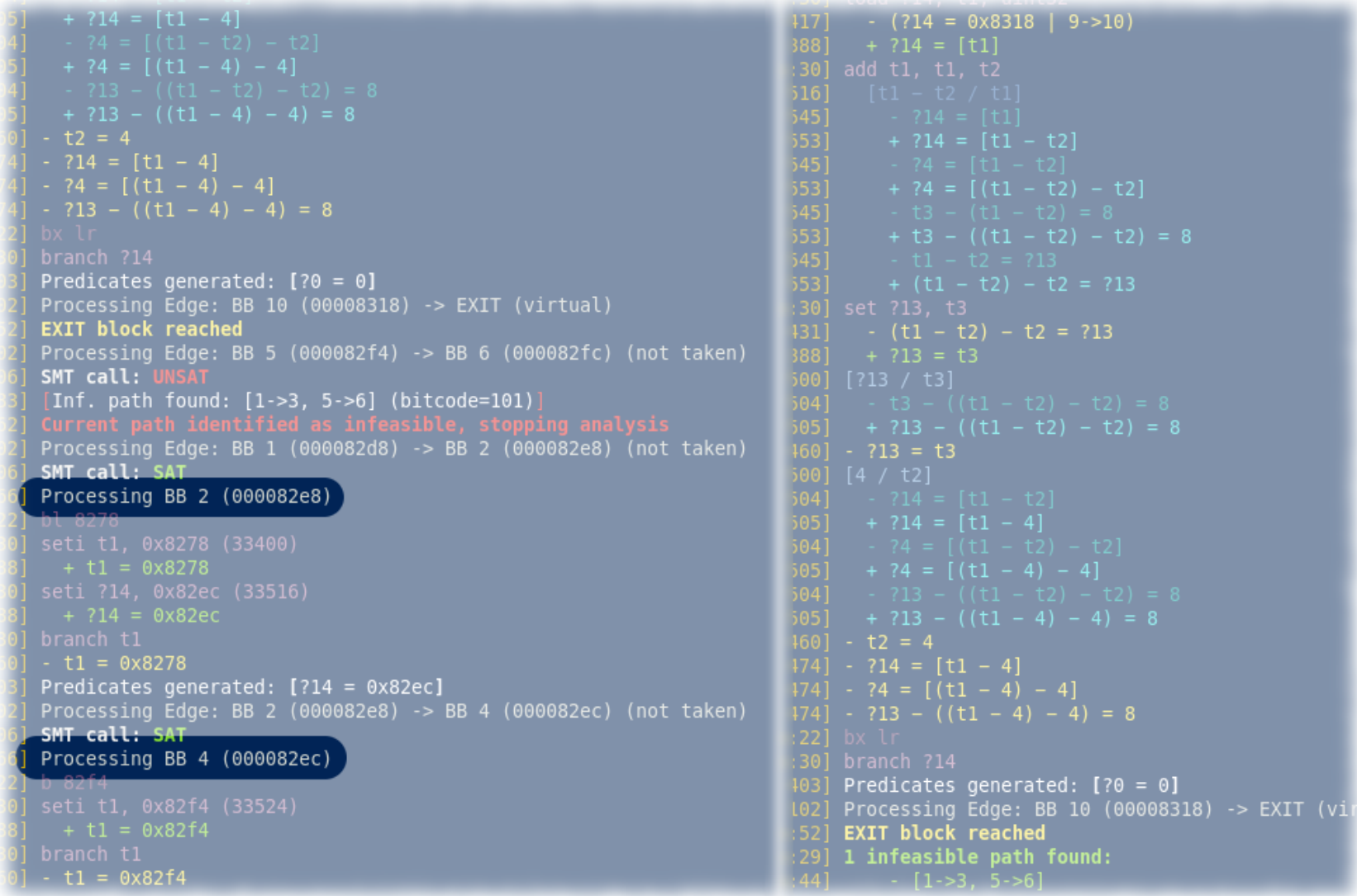
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add t1, t1, t2
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+ (t1 - t2) - t2 = ?13
set ?13, t3
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+ ?13 = t3
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- t3 - ((t1 - t2) - t2) = 8
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- ?13 = t3
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- ?14 = [t1 - t2]
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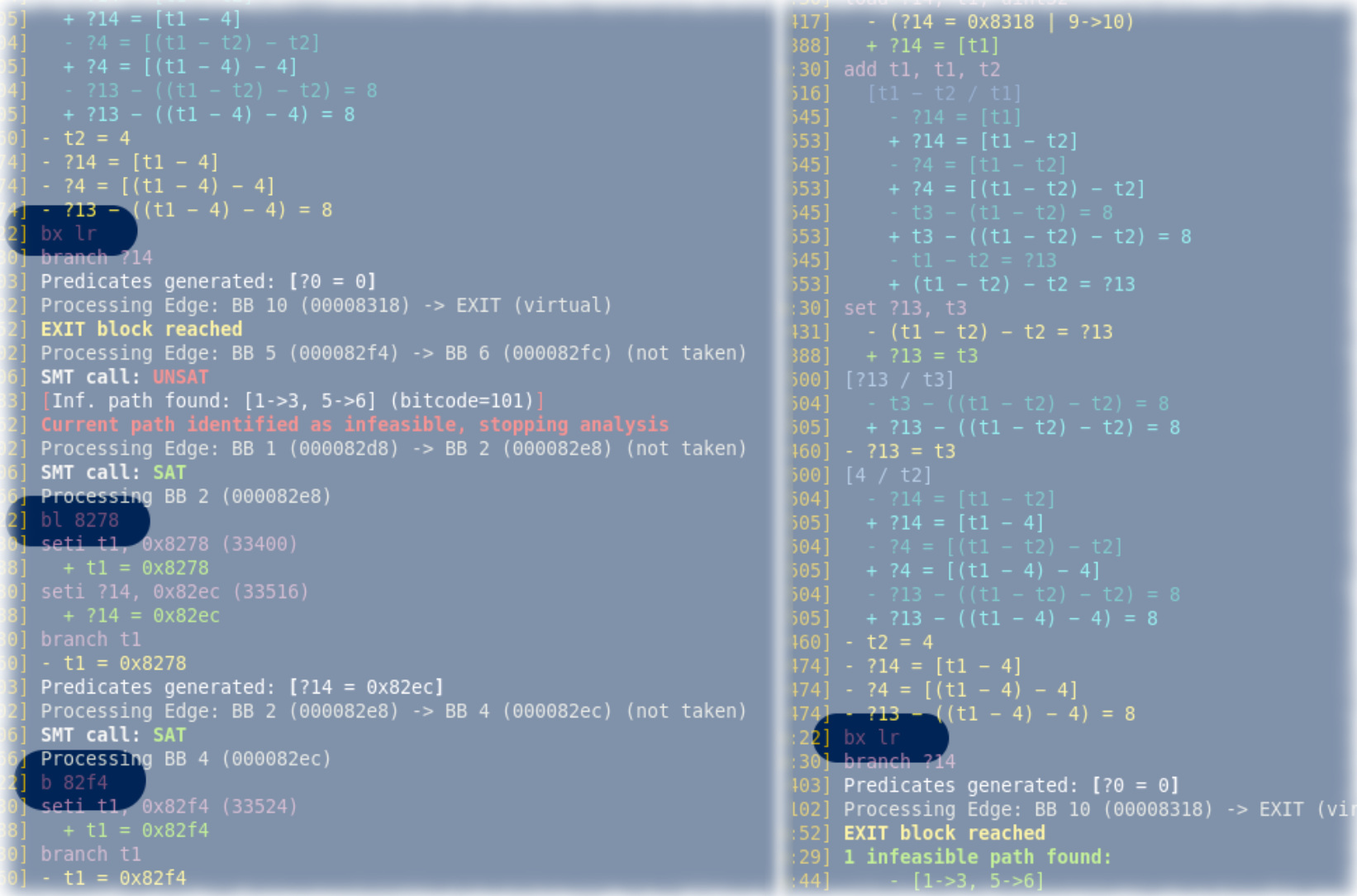
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branch t1
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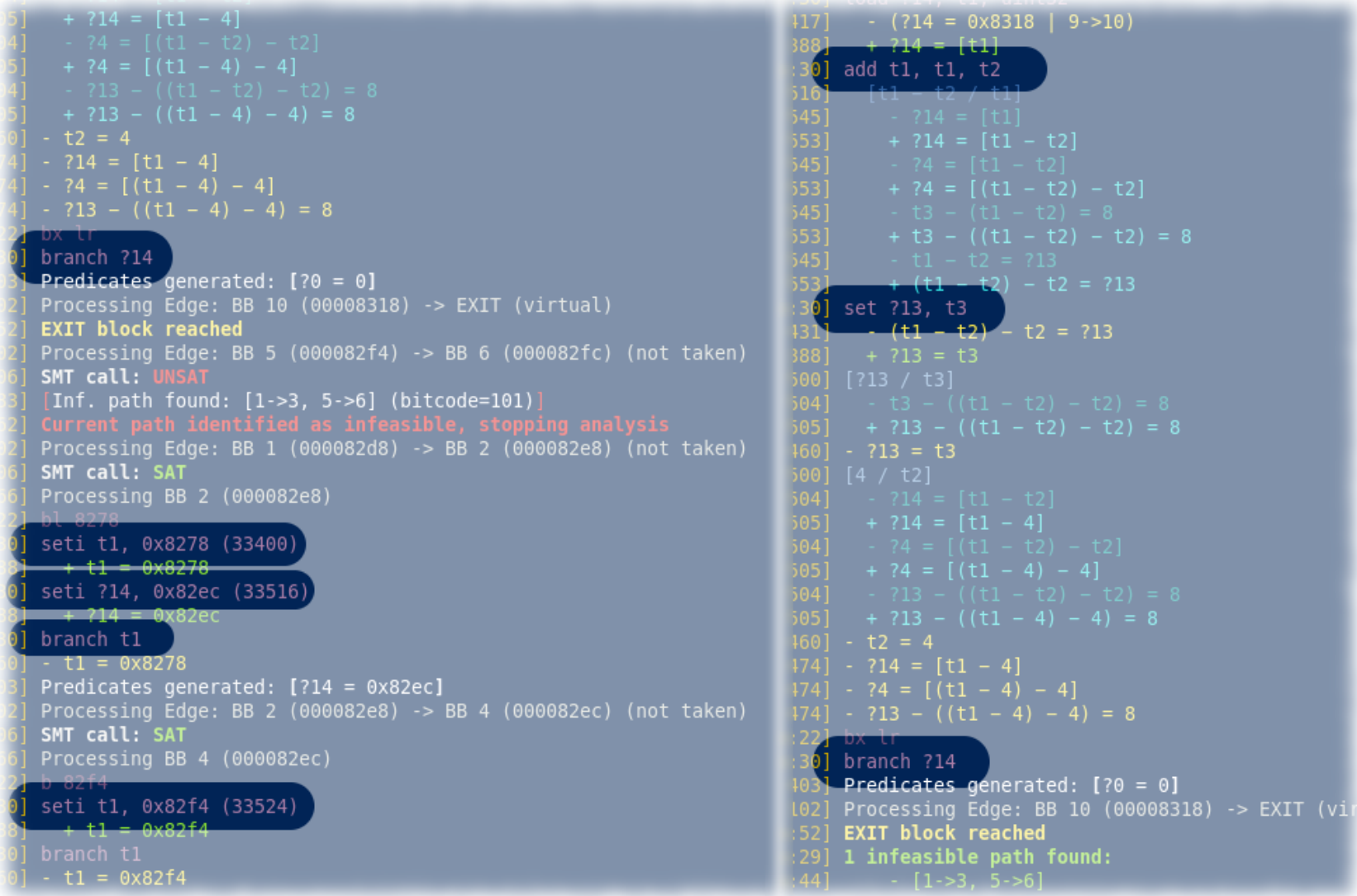
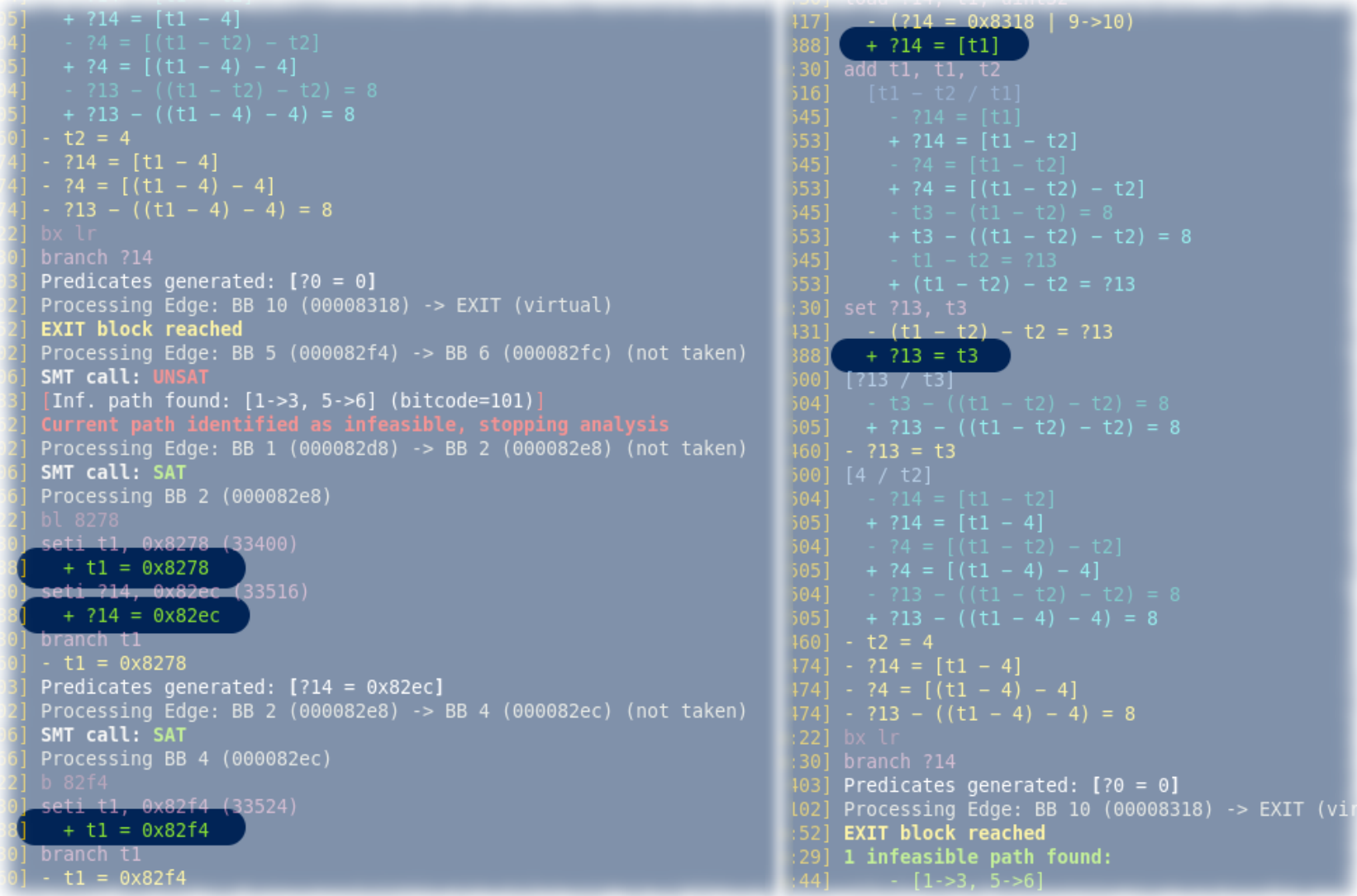
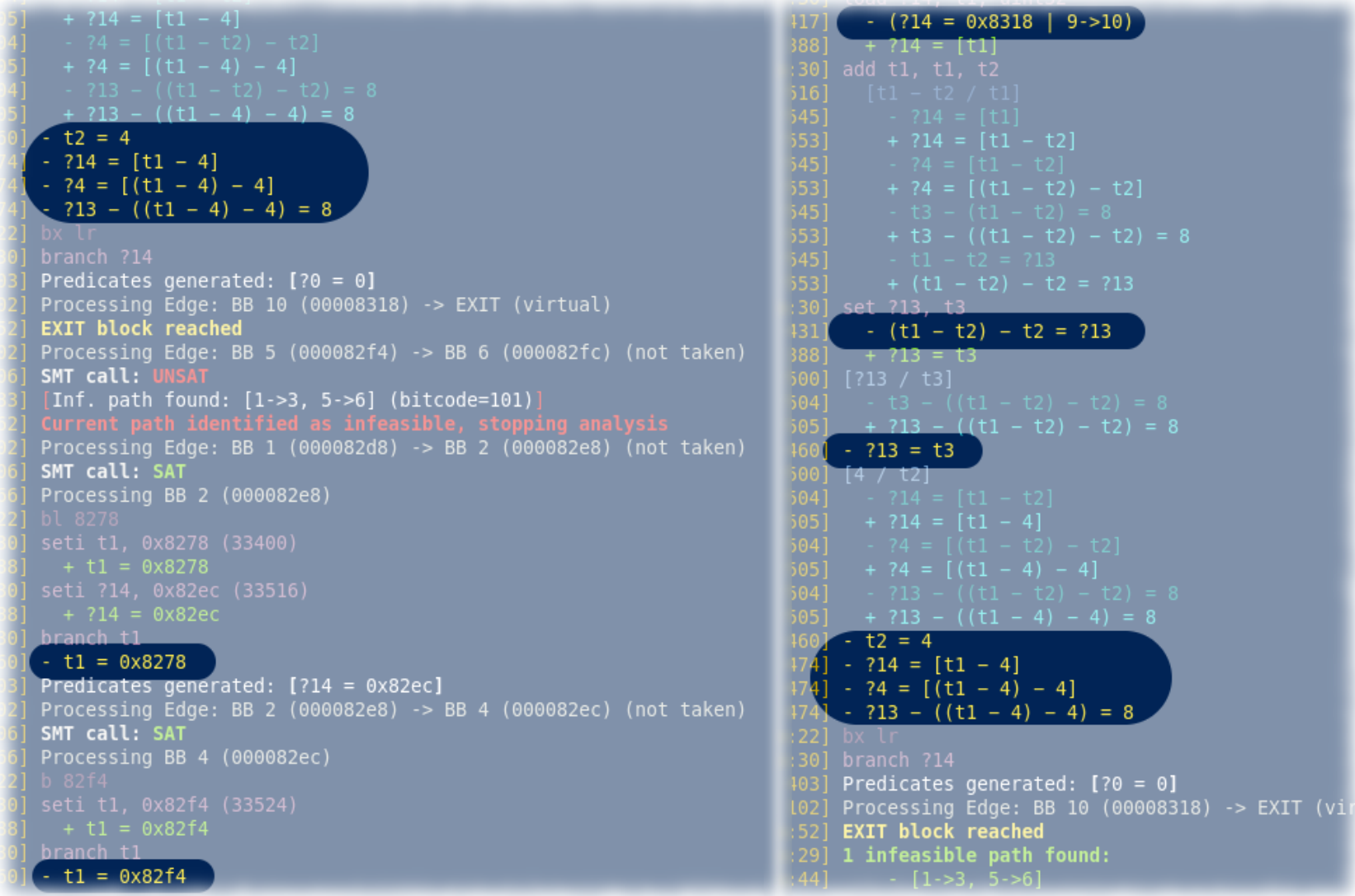
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
- [1->3, 5->6]


+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
+ t1 = 0x8278
seti ?14, 0x82ec (33516)
+ ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
+ t1 = 0x82f4
branch t1
- t1 = 0x82f4
- (?14 = 0x8318 | 9->10)
+ ?14 = [t1]
add t1, t1, t2
[t1 - t2 / t1]
- ?14 = [t1]
+ ?14 = [t1 - t2]
- ?4 = [t1 - t2]
+ ?4 = [(t1 - t2) - t2]
- t3 - (t1 - t2) = 8
+ t3 - ((t1 - t2) - t2) = 8
- t1 - t2 = ?13
+ (t1 - t2) - t2 = ?13
set ?13, t3
- (t1 - t2) - t2 = ?13
+ ?13 = t3
[?13 / t3]
- t3 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
- ?14 = [t1 - t2]
+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
- [1->3, 5->6]

```
05]   + ?14 = [t1 - 4]
04]   - ?4 = [(t1 - t2) - t2]
05]   + ?4 = [(t1 - 4) - 4]
04]   - ?13 - ((t1 - t2) - t2) = 8
05]   + ?13 - ((t1 - 4) - 4) = 8
60] - t2 = 4
74] - ?14 = [t1 - 4]
74] - ?4 = [(t1 - 4) - 4]
74] - ?13 - ((t1 - 4) - 4) = 8
22] bx lr
30] branch ?14
03] Predicates generated: [?0 = 0]
02] Processing Edge: BB 10 (00008318) -> EXIT (virtual)
52] EXIT block reached
02] Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
06] SMT call: UNSAT
33] [Inf. path found: [1->3, 5->6] (bitcode=101)]
52] Current path identified as infeasible, stopping analysis
02] Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
06] SMT call: SAT
66] Processing BB 2 (000082e8)
22] bl 8278
30] seti t1, 0x8278 (33400)
88]   + t1 = 0x8278
30] seti ?14, 0x82ec (33516)
88]   + ?14 = 0x82ec
30] branch t1
60] - t1 = 0x8278
03] Predicates generated: [?14 = 0x82ec]
02] Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
06] SMT call: SAT
66] Processing BB 4 (000082ec)
22] b 82f4
30] seti t1, 0x82f4 (33524)
88]   + t1 = 0x82f4
30] branch t1
60] - t1 = 0x82f4
```

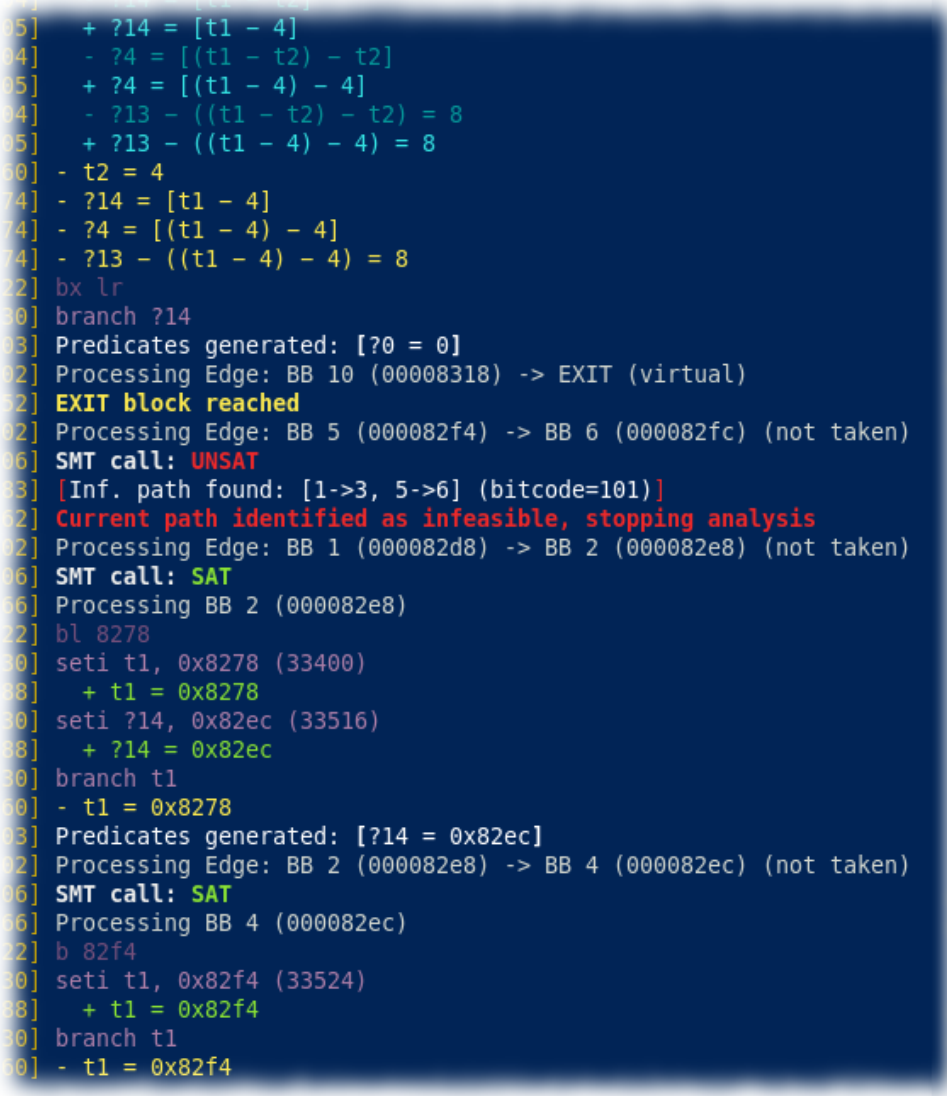
```
417]   - (?14 = 0x8318 | 9->10)
388]   + ?14 = [t1]
:30] add t1, t1, t2
516]   [t1 - t2 / t1]
545]     - ?14 = [t1]
553]     + ?14 = [t1 - t2]
545]     - ?4 = [t1 - t2]
553]     + ?4 = [(t1 - t2) - t2]
545]     - t3 - (t1 - t2) = 8
553]     + t3 - ((t1 - t2) - t2) = 8
545]     - t1 - t2 = ?13
553]     + (t1 - t2) - t2 = ?13
:30] set ?13, t3
431]   - (t1 - t2) - t2 = ?13
388]   + ?13 = t3
500] [?13 / t3]
504]   - t3 - ((t1 - t2) - t2) = 8
505]   + ?13 - ((t1 - t2) - t2) = 8
460] - ?13 = t3
500] [4 / t2]
504]   - ?14 = [t1 - t2]
505]   + ?14 = [t1 - 4]
504]   - ?4 = [(t1 - t2) - t2]
505]   + ?4 = [(t1 - 4) - 4]
504]   - ?13 - ((t1 - t2) - t2) = 8
505]   + ?13 - ((t1 - 4) - 4) = 8
460] - t2 = 4
474] - ?14 = [t1 - 4]
474] - ?4 = [(t1 - 4) - 4]
474] - ?13 - ((t1 - 4) - 4) = 8
:22] bx lr
:30] branch ?14
403] Predicates generated: [?0 = 0]
102] Processing Edge: BB 10 (00008318) -> EXIT (vir
:52] EXIT block reached
:29] 1 infeasible path found:
:44]     - [1->3, 5->6]
```

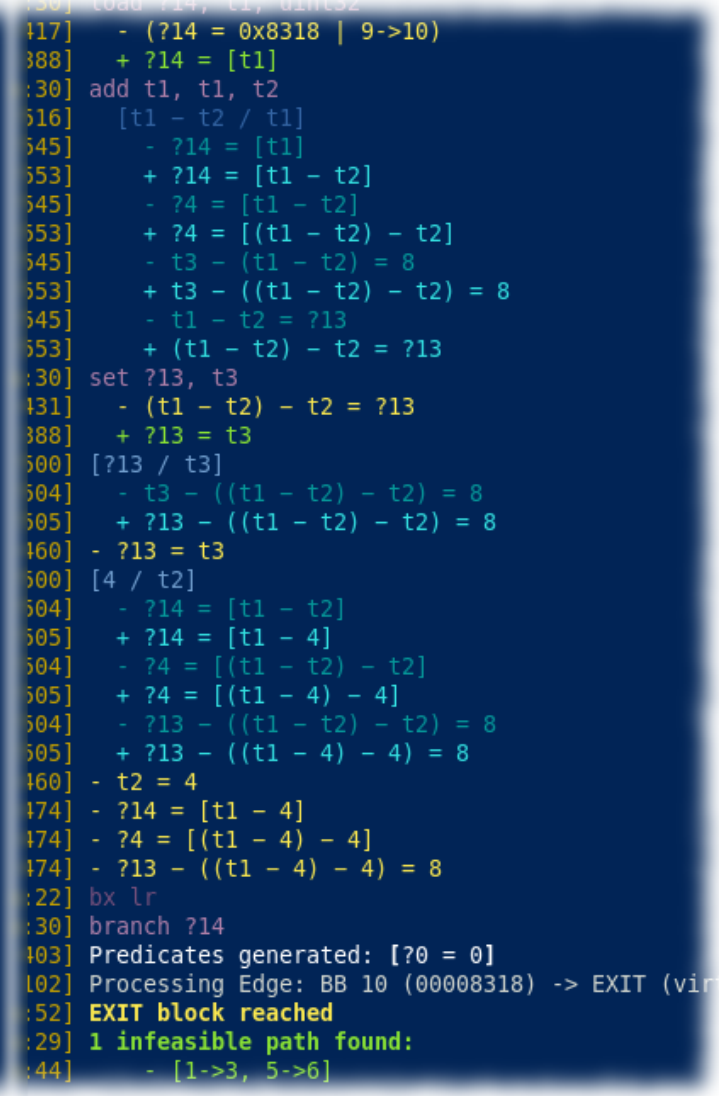

+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
+ t1 = 0x8278
seti ?14, 0x82ec (33516)
+ ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
+ t1 = 0x82f4
branch t1
- t1 = 0x82f4
- (?14 = 0x8318 | 9->10)
+ ?14 = [t1]
add t1, t1, t2
[t1 - t2 / t1]
- ?14 = [t1]
+ ?14 = [t1 - t2]
- ?4 = [t1 - t2]
+ ?4 = [(t1 - t2) - t2]
- t3 - (t1 - t2) = 8
+ t3 - ((t1 - t2) - t2) = 8
- t1 - t2 = ?13
+ (t1 - t2) - t2 = ?13
set ?13, t3
- (t1 - t2) - t2 = ?13
+ ?13 = t3
[?13 / t3]
- t3 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
- ?14 = [t1 - t2]
+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
- [1->3, 5->6]

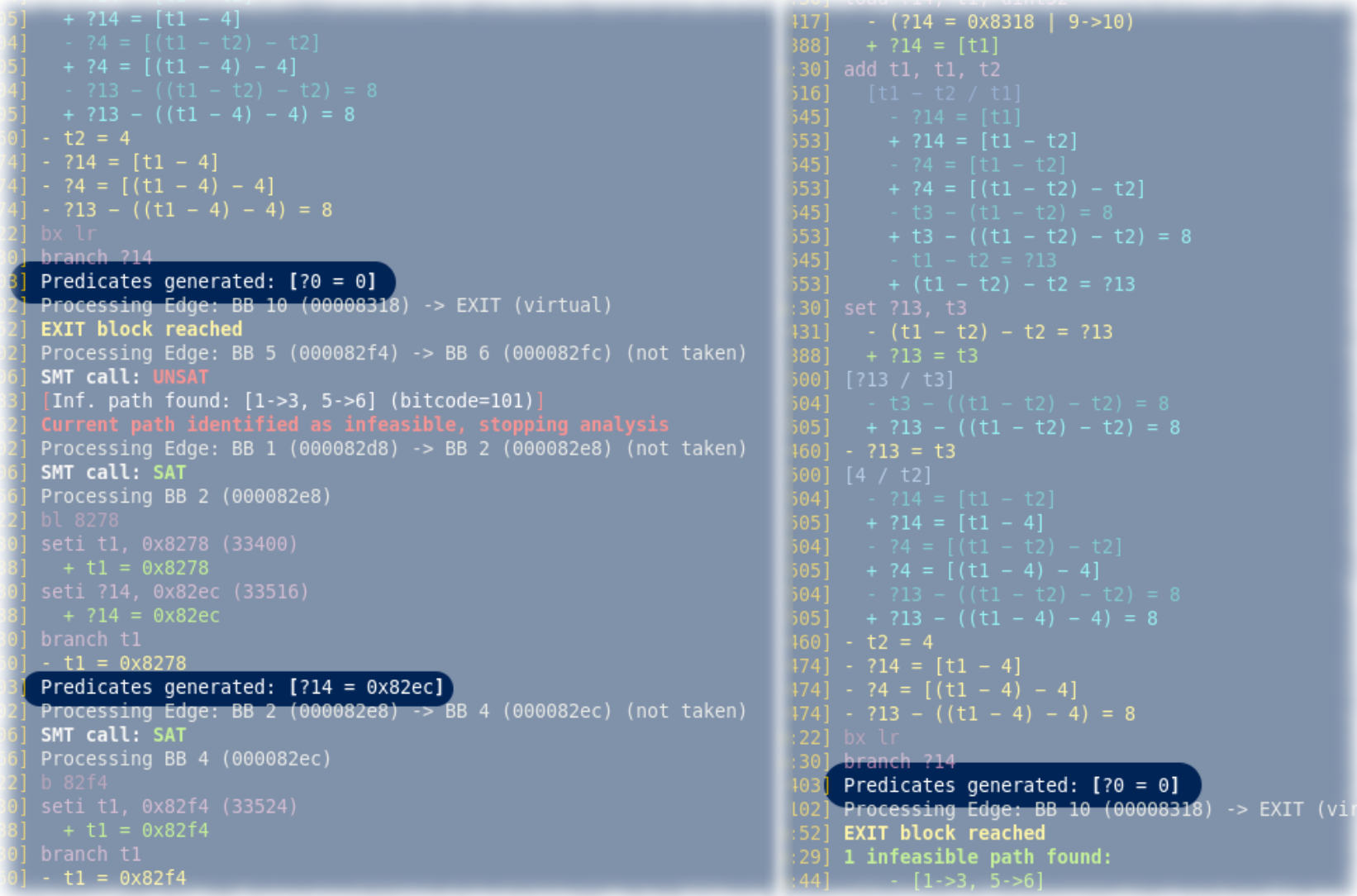

+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
+ t1 = 0x8278
seti ?14, 0x82ec (33516)
+ ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
+ t1 = 0x82f4
branch t1
- t1 = 0x82f4
- (?14 = 0x8318 | 9->10)
+ ?14 = [t1]
add t1, t1, t2
[t1 - t2 / t1]
- ?14 = [t1]
+ ?14 = [t1 - t2]
- ?4 = [t1 - t2]
+ ?4 = [(t1 - t2) - t2]
- t3 - (t1 - t2) = 8
+ t3 - ((t1 - t2) - t2) = 8
- t1 - t2 = ?13
+ (t1 - t2) - t2 = ?13
set ?13, t3
- (t1 - t2) - t2 = ?13
+ ?13 = t3
[?13 / t3]
- t3 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
- ?14 = [t1 - t2]
+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
- [1->3, 5->6]

```
   + ?14 = [t1 - 4]
   - ?4 = [(t1 - t2) - t2]
   + ?4 = [(t1 - 4) - 4]
   - ?13 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
  + t1 = 0x8278
seti ?14, 0x82ec (33516)
  + ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
  + t1 = 0x82f4
branch t1
- t1 = 0x82f4
```

```
  - (?14 = 0x8318 | 9->10)
  + ?14 = [t1]
add t1, t1, t2
  [t1 - t2 / t1]
    - ?14 = [t1]
    + ?14 = [t1 - t2]
    - ?4 = [t1 - t2]
    + ?4 = [(t1 - t2) - t2]
    - t3 - (t1 - t2) = 8
    + t3 - ((t1 - t2) - t2) = 8
    - t1 - t2 = ?13
    + (t1 - t2) - t2 = ?13
set ?13, t3
  - (t1 - t2) - t2 = ?13
  + ?13 = t3
[?13 / t3]
  - t3 - ((t1 - t2) - t2) = 8
  + ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
  - ?14 = [t1 - t2]
  + ?14 = [t1 - 4]
  - ?4 = [(t1 - t2) - t2]
  + ?4 = [(t1 - 4) - 4]
  - ?13 - ((t1 - t2) - t2) = 8
  + ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
    - [1->3, 5->6]
```


+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
+ t1 = 0x8278
seti ?14, 0x82ec (33516)
+ ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
+ t1 = 0x82f4
branch t1
- t1 = 0x82f4


- (?14 = 0x8318 | 9->10)
+ ?14 = [t1]
add t1, t1, t2
[t1 - t2 / t1]
- ?14 = [t1]
+ ?14 = [t1 - t2]
- ?4 = [t1 - t2]
+ ?4 = [(t1 - t2) - t2]
- t3 - (t1 - t2) = 8
+ t3 - ((t1 - t2) - t2) = 8
- t1 - t2 = ?13
+ (t1 - t2) - t2 = ?13
set ?13, t3
- (t1 - t2) - t2 = ?13
+ ?13 = t3
[?13 / t3]
- t3 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
- ?14 = [t1 - t2]
+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
- [1->3, 5->6]


+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
+ t1 = 0x8278
seti ?14, 0x82ec (33516)
+ ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
+ t1 = 0x82f4
branch t1
- t1 = 0x82f4
- (?14 = 0x8318 | 9->10)
+ ?14 = [t1]
add t1, t1, t2
[t1 - t2 / t1]
- ?14 = [t1]
+ ?14 = [t1 - t2]
- ?4 = [t1 - t2]
+ ?4 = [(t1 - t2) - t2]
- t3 - (t1 - t2) = 8
+ t3 - ((t1 - t2) - t2) = 8
- t1 - t2 = ?13
+ (t1 - t2) - t2 = ?13
set ?13, t3
- (t1 - t2) - t2 = ?13
+ ?13 = t3
[?13 / t3]
- t3 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
- ?14 = [t1 - t2]
+ ?14 = [t1 - 4]
- ?4 = [(t1 - t2) - t2]
+ ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - t2) - t2) = 8
+ ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
- [1->3, 5->6]

```
   + ?14 = [t1 - 4]
   - ?4 = [(t1 - t2) - t2]
   + ?4 = [(t1 - 4) - 4]
   - ?13 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
   + t1 = 0x8278
seti ?14, 0x82ec (33516)
   + ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
   + t1 = 0x82f4
branch t1
- t1 = 0x82f4
```

```
   - (?14 = 0x8318 | 9->10)
   + ?14 = [t1]
add t1, t1, t2
   [t1 - t2 / t1]
      - ?14 = [t1]
      + ?14 = [t1 - t2]
      - ?4 = [t1 - t2]
      + ?4 = [(t1 - t2) - t2]
      - t3 - (t1 - t2) = 8
      + t3 - ((t1 - t2) - t2) = 8
      - t1 - t2 = ?13
      + (t1 - t2) - t2 = ?13
set ?13, t3
   - (t1 - t2) - t2 = ?13
   + ?13 = t3
[?13 / t3]
   - t3 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
   - ?14 = [t1 - t2]
   + ?14 = [t1 - 4]
   - ?4 = [(t1 - t2) - t2]
   + ?4 = [(t1 - 4) - 4]
   - ?13 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
   - [1->3, 5->6]
```

```
   + ?14 = [t1 - 4]
   - ?4 = [(t1 - t2) - t2]
   + ?4 = [(t1 - 4) - 4]
   - ?13 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (virtual)
EXIT block reached
Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
SMT call: UNSAT
[Inf. path found: [1->3, 5->6] (bitcode=101)]
Current path identified as infeasible, stopping analysis
Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
SMT call: SAT
Processing BB 2 (000082e8)
bl 8278
seti t1, 0x8278 (33400)
   + t1 = 0x8278
seti ?14, 0x82ec (33516)
   + ?14 = 0x82ec
branch t1
- t1 = 0x8278
Predicates generated: [?14 = 0x82ec]
Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
SMT call: SAT
Processing BB 4 (000082ec)
b 82f4
seti t1, 0x82f4 (33524)
   + t1 = 0x82f4
branch t1
- t1 = 0x82f4
```

```
   - (?14 = 0x8318 | 9->10)
   + ?14 = [t1]
add t1, t1, t2
   [t1 - t2 / t1]
      - ?14 = [t1]
      + ?14 = [t1 - t2]
      - ?4 = [t1 - t2]
      + ?4 = [(t1 - t2) - t2]
      - t3 - (t1 - t2) = 8
      + t3 - ((t1 - t2) - t2) = 8
      - t1 - t2 = ?13
      + (t1 - t2) - t2 = ?13
set ?13, t3
   - (t1 - t2) - t2 = ?13
   + ?13 = t3
[?13 / t3]
   - t3 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - t2) - t2) = 8
- ?13 = t3
[4 / t2]
   - ?14 = [t1 - t2]
   + ?14 = [t1 - 4]
   - ?4 = [(t1 - t2) - t2]
   + ?4 = [(t1 - 4) - 4]
   - ?13 - ((t1 - t2) - t2) = 8
   + ?13 - ((t1 - 4) - 4) = 8
- t2 = 4
- ?14 = [t1 - 4]
- ?4 = [(t1 - 4) - 4]
- ?13 - ((t1 - 4) - 4) = 8
bx lr
branch ?14
Predicates generated: [?0 = 0]
Processing Edge: BB 10 (00008318) -> EXIT (vir
EXIT block reached
1 infeasible path found:
   - [1->3, 5->6]
```

```
05]   + ?14 = [t1 - 4]
04]   - ?4 = [(t1 - t2) - t2]
05]   + ?4 = [(t1 - 4) - 4]
04]   - ?13 - ((t1 - t2) - t2) = 8
05]   + ?13 - ((t1 - 4) - 4) = 8
60] - t2 = 4
74] - ?14 = [t1 - 4]
74] - ?4 = [(t1 - 4) - 4]
74] - ?13 - ((t1 - 4) - 4) = 8
22] bx lr
30] branch ?14
03] Predicates generated: [?0 = 0]
02] Processing Edge: BB 10 (00008318) -> EXIT (virtual)
52] EXIT block reached
02] Processing Edge: BB 5 (000082f4) -> BB 6 (000082fc) (not taken)
06] SMT call: UNSAT
83] [Inf. path found: [1->3, 5->6] (bitcode=101)]
62] Current path identified as infeasible, stopping analysis
02] Processing Edge: BB 1 (000082d8) -> BB 2 (000082e8) (not taken)
06] SMT call: SAT
66] Processing BB 2 (000082e8)
22] bl 8278
30] seti t1, 0x8278 (33400)
88]   + t1 = 0x8278
30] seti ?14, 0x82ec (33516)
88]   + ?14 = 0x82ec
30] branch t1
60] - t1 = 0x8278
03] Predicates generated: [?14 = 0x82ec]
02] Processing Edge: BB 2 (000082e8) -> BB 4 (000082ec) (not taken)
06] SMT call: SAT
66] Processing BB 4 (000082ec)
22] b 82f4
30] seti t1, 0x82f4 (33524)
88]   + t1 = 0x82f4
30] branch t1
60] - t1 = 0x82f4
```

```
417]   - (?14 = 0x8318 | 9->10)
388]   + ?14 = [t1]
:30] add t1, t1, t2
516]   [t1 - t2 / t1]
545]     - ?14 = [t1]
553]     + ?14 = [t1 - t2]
545]     - ?4 = [t1 - t2]
553]     + ?4 = [(t1 - t2) - t2]
545]     - t3 - (t1 - t2) = 8
553]     + t3 - ((t1 - t2) - t2) = 8
545]     - t1 - t2 = ?13
553]     + (t1 - t2) - t2 = ?13
:30] set ?13, t3
431]   - (t1 - t2) - t2 = ?13
388]   + ?13 = t3
500] [?13 / t3]
504]   - t3 - ((t1 - t2) - t2) = 8
505]   + ?13 - ((t1 - t2) - t2) = 8
460] - ?13 = t3
500] [4 / t2]
504]   - ?14 = [t1 - t2]
505]   + ?14 = [t1 - 4]
504]   - ?4 = [(t1 - t2) - t2]
505]   + ?4 = [(t1 - 4) - 4]
504]   - ?13 - ((t1 - t2) - t2) = 8
505]   + ?13 - ((t1 - 4) - 4) = 8
460] - t2 = 4
474] - ?14 = [t1 - 4]
474] - ?4 = [(t1 - 4) - 4]
474] - ?13 - ((t1 - 4) - 4) = 8
:22] bx lr
:30] branch ?14
403] Predicates generated: [?0 = 0]
102] Processing Edge: BB 10 (00008318) -> EXIT (vir
:52] EXIT block reached
:29] 1 infeasible path found:
:44]     - [1->3, 5->6]
```

Plan

Extensions

- Thèse future dans la continuation du stage M2R, beaucoup d'extensions à faire :

Extensions

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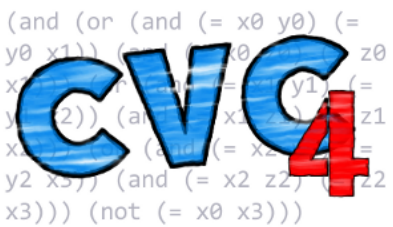

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  - Appels au solveur SMT plus intelligents
  - Gérer les spécificités des types de données du langage machine
  - Générer des contraintes ILP ne **suffit plus**
    $\Longrightarrow$ il faudrait faire de la **réécriture de graphe**.

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- À poursuivre en thèse...


Questions ?