```



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***                                               ***
***  Demonstration of the Astree static analyzer   ***
***           http://www.astree.ens.fr/           ***
***                                               ***
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*** A. Mine, X. Rival [2001--]                     ***
*** [B. Blanchet (2001/03), D. Monniaux (2001/07)] ***
***                                               ***
*****************************************************
*****************************************************
%

*******************************************
* Astree is a VERIFIER (not a bug-finder). *
* Astree is SOUND hence should report ALL  *
* potential runtime errors.                *
*******************************************
%

*** example [CC76]:

% cat -n dichotomy-error.c
     1 /* dichotomy-error.c */
     2 int main () {
     3    int lwb, upb, m, R[100], X;
     4    lwb = 1; upb = 100;
     5    while (lwb <= upb) {
     6       m = (upb + lwb) / 2;
     7       if (X == R[m]) {
     8          upb = m; lwb = m+1; }
     9       else if (X < R[m]) {
    10          upb = m - 1; }
    11       else {
    12          lwb = m + 1; }
    13    }
    14    __ASTREE_log_vars((m));
    15 }
%

*** static analysis by Astree:

% astree --exec-fn main --no-relational --unroll 0 dichotomy-error.c \
  |& egrep --after-context 0 "(launched)|(WARN)"

dichotomy-error.c:7.15-19::[call#main@2:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [4;400] may overflow the variable R of byte-size 400
dichotomy-error.c:7.15-19::[call#main@2:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [4;400] may overflow the variable R of byte-size 400
dichotomy-error.c:9.19-23::[call#main@2:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [4;400] may overflow the variable R of byte-size 400
dichotomy-error.c:9.19-23::[call#main@2:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [4;400] may overflow the variable R of byte-size 400
%

*** (the two errors are reported two times each
***  for the two branches of the conditional.)
%

*** correcting the error:

% cat -n dichotomy.c
     1 /* dichotomy.c */
     2 int main () {
     3    int lwb, upb, m, R[100], X;
     4    lwb = 0; upb = 99;
     5    while (lwb <= upb) {
```

```
     6        m = (upb + lwb) / 2;
     7        if (X == R[m]) {
     8           upb = m; lwb = m+1; }
     9        else if (X < R[m]) {
    10           upb = m - 1; }
    11        else {
    12           lwb = m + 1; }
    13     }
    14     __ASTREE_log_vars((m));
    15 }
%

*** correction (difference with the erroneous version):

% diff dichotomy-error.c dichotomy.c
1c1
< /* dichotomy-error.c */
---
> /* dichotomy.c */
4c4
<    lwb = 1; upb = 100;
---
>    lwb = 0; upb = 99;
%

*** static analysis by Astree:

% astree --exec-fn main --no-relational dichotomy.c \
  |& egrep "(launched)|(m in )|(WARN)"

direct = <integers (intv+cong+bitfield+set): m in [0, 99] >
%

*****************************************************
* Astree is INCOMPLETE hence may report false alarms *
*****************************************************
%

*** example of false alarm:

% cat -n fausse-alarme.c
     1 /* fausse-alarme.c */
     2 void main()
     3 {
     4   int x, y;
     5   if ((-4681 < y) && (y < 4681) && (x < 32767) && (-32767 < x) && ((7*y*y - 1) == x*x)) {
     6      y = 1 / x;
     7   };
     8 }
%

*** static analysis by Astree:

% astree --exec-fn main fausse-alarme.c |& egrep "(launched)|(WARN)"

fausse-alarme.c:6.9-14::[call#main@2:]: WARN: integer division by zero [-32766, 32766]
%

**********************************************
* Astree tracks all potential buffer overruns *
**********************************************
%

*** example of uninitialization and buffer overrun:

% cat -n bufferoverrun-c.c
     1 #include <stdio.h>
     2 int main () {
     3 int x, y, z, T[9];
     4 x = T[7];
     5 y = T[8];
     6 z = T[9];
     7 printf("x = %i, y = %i, z = %i\n",x,y,z);
     8 }
     9
%

*** compilation and execution:

% gcc bufferoverrun-c.c
% ./a.out
x = 4096, y = 0, z = 4096
%

*** static analysis with Astree:

% cat -n bufferoverrun.c
     1 int main () {
     2 int a, x, y, z, T[9];
     3 x = T[7];
     4 y = T[8];
     5 z = T[9];
     6 __ASTREE_log_vars((x,y,z));
     7 }
     8
%

% astree --exec-fn main bufferoverrun.c\
  |& egrep "(x in)|(y in)|(z in)|(WARN)"
bufferoverrun.c:5.4-8::[call#main@1:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [36;36] may overflow the variable T of byte-size 36
%
*** Astree signals the definite error and considers the
*** (unpredictable) execution to be stopped (so no log).
%

************************************************
* Astree tracks all potential dangling pointers *
************************************************
%

*** example of dangling pointer:

% cat -n danglingpointer-c.c
     1 #include <stdio.h>
     2 int main () {
     3 int x, y, z, *r;
     4 x = 100;
     5 r = &x;
     6 y = *r;
     7 z = *(r+2);
     8 printf("x = %i, y = %i, z = %i\n",x,y,z);
     9 }
    10
%

*** compilation and execution:

% gcc danglingpointer-c.c
% ./a.out
x = 100, y = 100, z = -1073748436
%

*** static analysis with Astree:

% cat -n danglingpointer.c
     1 int main () {
     2 int x, y, z, *r;
     3 x = 100;
     4 r = &x;
     5 y = *r;
     6 z = *(r+2);
     7 __ASTREE_log_vars((x,y,z));
     8 }
     9
%

% astree --exec-fn main danglingpointer.c\
  |& egrep "(x in)|(y in)|(z in)|(WARN)"
danglingpointer.c:6.4-10::[call#main@1:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [8;8] may overflow the variable x of byte-size 4
%
*** Astree signals the definite error and considers the
*** (unpredictable) execution to be stopped (so no log).
%

*********************************************
* Astree uses a predictable semantics of C  *
* conforming with the standard and with the *
* implementation but only in absence of     *
* unpredictable runtime errors.             *
*********************************************
%

% cat -n Unsafe1.c
     1 int A[4], c;
     2 void bad(int *p, int x, int y) {
     3   p[4] = x;
     4   if( c!=0 ) {
     5      A[1003] = y;
     6   }
     7 }
     8 void ok(int *q, int n) {
     9    c = 0;
    10    q[0] = n;
    11 }
    12 int main() {
    13   ok(A,0);
    14   bad(A,1,0);
    15 }
%

*** Which errors should be raised by Astree?

% astree --exec-fn main Unsafe1.c |& egrep "(launched)|(WARN)"

Unsafe1.c:3.9-10::[call#main@12:call#bad@14:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [16;16] may overflow the variable A of byte-size 16
%
***********************************************
* 5: never executed                           *
***********************************************

% cat -n Unsafe2.c
     1 int A[4], c;
     2 void bad(int *p, int x, int y) {
     3   p[4] = x;
     4   if( c!=0 ) {
     5      A[1003] = y;
     6   }
     7 }
     8 void ok(int *q, int n) {
     9    c = 1;
    10    q[0] = n;
    11 }
    12 int main() {
    13   ok(A,0);
    14   bad(A,1,0);
    15 }
%

*** Which errors should be raised by Astree?
```

```
% astree --exec-fn main Unsafe2.c |& egrep "(launched)|(WARN)"

Unsafe2.c:3.9-10::[call#main@12:call#bad@14:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [16;16] may overflow the variable A of byte-size 16
%
**********************************************
* Execution stops at 3: with a definite error, *
* 5: can be executed in some implementations.  *
**********************************************


% cat -n Unsafe3.c
     1 int A[4], c;
     2 void bad(int *p, int x, int y) {
     3   p[3] = x;
     4   if( c!=0 ) {
     5      A[1003] = y;
     6   }
     7 }
     8 void ok(int *q, int n) {
     9
    10    q[0] = n;
    11 }
    12 int main() {
    13   ok(A,0);
    14   bad(A,1,0);
    15 }
%

*** Which errors should be raised by Astree?

% astree --exec-fn main Unsafe3.c |& egrep "(launched)|(WARN)"

%
**********************************************
* c implicitly initialized to 0.             *
**********************************************

*** Static analysis by Astree without implicit
*** initialization of globals to zero:

% astree --exec-fn main --no-global-initialization Unsafe3.c |& egrep "(launched)|(WARN)"

Unsafe3.c:5.15-16::[call#main@12:call#bad@14:]: WARN: invalid dereference: dereferencing 4 byte(s) at offset(s) [4012;4012] may overflow the variable A of byte-size 16
%
**********************************************
* A and c now uninitialized.                 *
**********************************************

****************************************************
* Astree tracks potential modulo arithmetics errors *
****************************************************
%

*** Modulo arithmetics is not very intuitive:

% cat -n modulo-c.c
     1 #include <stdio.h>
     2 int main () {
     3 int x,y;
     4 x = -2147483647 / -1;
     5 y = ((-x) -1) / -1;
     6 printf("x = %i, y = %i\n",x,y);
     7 }
     8
%

*** compilation and execution:

% gcc modulo-c.c
% ./a.out
x = 2147483647, y = -2147483648
%
*** -2147483648 / -1 = -2147483648 ???
%

*** static analysis with Astree:

% cat -n modulo.c
     1 int main () {
     2 int x,y;
     3 x = -2147483647 / -1;
     4 y = ((-x) -1) / -1;
     5 __ASTREE_log_vars((x,y));
     6 }
     7
%

% astree --exec-fn main --unroll 0 modulo.c\
  |& egrep -A 1 "(<integers)|(WARN)"
modulo.c:4.4-18::[call#main@1:]: WARN: signed int arithmetic range {2147483648} not included in [-2147483648, 2147483647]
modulo.c:5.0-24: log:
--
  <integers (intv+cong+bitfield+set): y in [-2147483648, 2147483647],
   x in {2147483647} >
%
*** Astree signals the error and goes on predictively
*** but with an unkown value (hence the log)
%

******************************************
* Astree uses interval analysis (enhanced *
* by symbolic execution)                  *
******************************************

*** example:

% cat -n interval.c
     1 int main () {
     2  int x, y;
     3  __ASTREE_known_fact(((0 <= x) && (x <= 100)));
     4  y = x - x;
     5  __ASTREE_log_vars((x,y));
     6 }
%

*** static analysis by Astree (1 -- WITHOUT symbolic execution):

% astree interval.c --no-relational --exec-fn main \
  |& egrep "(launched)|(x in)|(y in)"

  <integers (intv+cong+bitfield+set): y in [-100, 100], x in [0, 100] >
%

*** static analysis by Astree (2 -- WITH symbolic execution):

% astree interval.c --exec-fn main \
  |& egrep "(launched)|(y in)"

direct = <integers (intv+cong+bitfield+set): y in {0}, x in [0, 100] >
%

*** The symbolic abstract domain propagates the
*** symbolic value of variables (plus rounding
*** errors) to perform simplifications.
%

*********************************************************
* Astree uses the reduction of [non]Ðrelational abstract *
* domains such as intervals and congruences              *
```

```
**********************************************************
%

*** example:

% cat -n congruence.c
     1 /* congruence.c */
     2 int main()
     3 { int X;
     4   X = 0;
     5   while (X <= 128)
     6     { X = X + 4; };
     7   __ASTREE_log_vars((X));
     8 }
%

*** static analysis by Astree:

% astree congruence.c --no-relational --exec-fn main |& egrep "(launched)|(WARN)|(X in)"

direct = <integers (intv+cong+bitfield+set): X in {132} >
%

*****************************************
* Astree uses weakly relational abstract *
* domains such as octagons...            *
*****************************************

*** example:

% cat -n octagon.c
     1 /* octagon.c */
     2 void main()
     3 {
     4   int X, Y;
     5   X = 10;
     6   Y = 100;
     7   while (X >= 0) {
     8     X--;
     9     Y--;
    10   };
    11   __ASTREE_assert((X <= Y));
    12 }
%

*** static analysis by Astree (1 -- WITHOUT octagons):

% astree octagon.c --no-octagon --exec-fn main |& egrep "(launched)|(WARN)"

octagon.c:9.4-7::[call#main@2:loop@7>=4:]: WARN: signed int arithmetic range [-2147483649, 2147483646] not included in [-2147483648, 2147483647]
octagon.c:11.19-25::[call#main@2:]: WARN: assert failure
%

*** static analysis by Astree (2 -- WITH octagons):

% astree octagon.c --exec-fn main |& egrep "(launched)|(WARN)"

%
*** Does not scale up to too many variables,
***  --> packs of variables.
%

*** static analysis by Astree (3 -- octagon packs):

% astree octagon.c --exec-fn main --print-packs |& egrep -A 2 "List of packs"
List of packs
  octagon.c@4@5 { X Y }
Size of packs [ 2 (octagon.c@4@5) ]
--
List of packs
```

```
Size of packs [ ]
Occurence of each variable [ ]
%

*********************************************
* Astree uses weakly relational abstract    *
* domains such as boolean decision trees... *
*********************************************
%

*** example:

% cat -n boolean.c
     1 /* boolean.c */
     2 typedef enum {F=0,T=1} BOOL;
     3 BOOL B;
     4 void main () {
     5    unsigned int X, Y;
     6    while (1) {
     7       /* ... */
     8       B = (X == 0);
     9       /* ... */
    10       if (!B) {
    11          Y = 1 / X;
    12       }
    13       /* ... */
    14    }
    15 }
%

*** static analysis by Astree (1 -- **WITHOUT**
*** decision trees):

% astree boolean.c --no-relational --exec-fn main |& egrep "(launched)|(WARN)"

boolean.c:11.13-18::[call#main@4:loop@6=1:]: WARN: integer division by zero [0, 4294967295]
boolean.c:11.13-18::[call#main@4:loop@6=2:]: WARN: integer division by zero [0, 4294967295]
boolean.c:11.13-18::[call#main@4:loop@6=3:]: WARN: integer division by zero [0, 4294967295]
boolean.c:11.13-18::[call#main@4:loop@6>=4:]: WARN: integer division by zero [0, 4294967295]
%

*** static analysis by Astree (2 -- **WITH**
*** decision trees):

% astree boolean.c --exec-fn main |& egrep "(launched)|(WARN)"

%

**********************************************
* Astree uses computation trace abstractions *
* (describing  sequences of states) not only *
* invariants (describing sets of states)     *
**********************************************
%

*** example:

% cat -n trace-partitioning.c
     1 void main() {
     2 float t[5] = {-10.0, -10.0, 0.0, 10.0, 10.0};
     3 float c[4] = {0.0, 2.0, 2.0, 0.0};
     4 float d[4] = {-20.0, -20.0, 0.0, 20.0};
     5 float x, r;
     6   __ASTREE_known_fact(((-30.0 <= x) && (x <= 30.0)));
     7   int i = 0;
     8   while ((i < 3) && (x >= t[i+1])) {
     9     i = i + 1;
    10   }
    11   r = (x - t[i]) * c[i] + d[i];
    12   __ASTREE_log_vars((r));
    13 }
```

```
%

*** static analysis by Astree (1 -- **WITH**
*** partitioning):

% astree --exec-fn main --no-trace --no-relational trace-partitioning.c \
  |& egrep "(launched)|(WARN)|(r in)"

/* Domains: Linearization, and Integer intervals, and congruences, and bitfields, and finite integer sets, and Float intervals. */
direct = <float-interval: r in [-20., 20.] >
%

*** static analysis by Astree (2 -- **WITHOUT**
*** partitioning):

% astree --exec-fn main --no-partition --no-trace --no-relational trace-partitioning.c \
  |& egrep "(launched)|(WARN)|(r in)"

/* Domains: Linearization, and Integer intervals, and congruences, and bitfields, and finite integer sets, and Float intervals. */
direct = <float-interval: r in [-100., 100.] >
%

*** static analysis by Astree (3 -- automatic
*** insertion of partitioning directives):

astree --exec-fn main --dump-partition trace-partitioning.c \
  |& egrep --after-context 17 "void"
void (main)()
{
  float (t[5]) = { -1.000000e+01, -1.000000e+01, 0.000000e+00, 1.000000e+01, 1.000000e+01};
  float (c[4]) = { 0.000000e+00, 2.000000e+00, 2.000000e+00, 0.000000e+00};
  float (d[4]) = { -2.000000e+01, -2.000000e+01, 0.000000e+00, 2.000000e+01};
  float x;
  float r;
  __ASTREE_known_fact((((-30. <= x) && (x <= 30.))));
  signed int i = 0;
  __ASTREE_partition_control((15))
  while (((i < 3) && (x >= t[(i + 1)])))
  {
    i = (i + 1);
  }
  r = (((x - t[i]) * c[i]) + d[i]);
  __ASTREE_partition_merge(());
  __ASTREE_log_vars((r));
}
%

************************************************
* Astree tracks potential overflows with floats *
************************************************
%

*** Floats arithmetics does overflow:

% cat -n overflow-c.c
     1 #include <stdio.h>
     2 int main () {
     3 double x,y;
     4 x = 1.0e+256 * 1.0e+256;
     5 y = 1.0e+256 * -1.0e+256;
     6 printf("x = %f, y = %f\n",x,y);
     7 }
     8
%

*** compilation and execution:

% gcc overflow-c.c
./a.out
```

```
x = inf, y = -inf
%

*** static analysis with Astree:

% cat -n overflow.c
     1 int main () {
     2 double x,y;
     3 x = 1.0e+256 * 1.0e+256;
     4 y = 1.0e+256 * -1.0e+256;
     5 __ASTREE_log_vars((x,y));
     6 }
%

% astree --exec-fn main  overflow.c |& grep "WARN"
overflow.c:3.4-23::[call#main@1:]: WARN: double arithmetic range [1.7976932e+308, inf.] not included in [-1.7976931e+308, 1.7976932e+308]
overflow.c:4.4-24::[call#main@1:]: WARN: double arithmetic range [-inf., -1.7976931e+308] not included in [-1.7976931e+308, 1.7976932e+308]
%
*** Potential computations with inf, -inf, nan, etc
*** are always signalled by Astree as potential errors.
*** Volatiles are assumed not to be inf, -inf, nan.
%

***************************************************
* Astree handles floats, not reals or fixed point *
* arithmetics                                     *
***************************************************
%

*** example of computation error in floats:
***   (x+a)-(x-a) <> 2a! with float
%

% cat -n float-float-c.c
     1 /* float-float-c.c */
     2 #include <stdio.h>
     3 int main () {
     4 float x; float a, y, z, r1, r2;
     5 a = 1.0;
     6 x = 1125899973951488.0;
     7 y = (x + a);
     8 z = (x - a);
     9 r1 = y - z;
    10 r2 = 2 * a;
    11 printf("(x + a) - (x - a) = %f\n", r1);
    12 printf("2a                = %f\n", r2);
    13 }
%

*** compilation and execution:

% gcc float-float-c.c
% ./a.out
(x + a) - (x - a) = 0.000000
2a                = 2.000000
%

*** more precision can be better...
***   (x+a)-(x-a) = 2a with double
%

% cat -n double-double-c.c
     1 /* double-double-c.c */
     2 #include <stdio.h>
     3 int main () {
     4 double x; double a, y, z, r1, r2;
     5 a = 1.0;
     6 x = 1125899973951488.0;
     7 y = (x + a);
     8 z = (x - a);
     9 r1 = y - z;
    10 r2 = 2 * a;
    11 printf("(x + a) - (x - a) = %f\n", r1);
    12 printf("2a                = %f\n", r2);
    13 }
%

*** compilation and execution:

% ./a.out
% gcc double-double-c.c
(x + a) - (x - a) = 2.000000
2a                = 2.000000
%

*** computations with different precisions...
*** can be really catastrophic!
***   (x+a)-(x-a) <> 2a! with double+float
%

% cat -n double-float-c.c
     1 /* double-float.c */
     2 #include <stdio.h>
     3 int main () {
     4 double x; float a, y, z, r1, r2;
     5 a = 1.0;
     6 x = 1125899973951488.0;
     7 y = (x + a);
     8 z = (x - a);
     9 r1 = y - z;
    10 r2 = 2 * a;
    11 printf("(x + a) - (x - a) = %f\n", r1);
    12 printf("2a                = %f\n", r2);
    13 }
%

*** compilation and execution:

% gcc double-float-c.c
% ./a.out
(x + a) - (x - a) = 134217728.000000
2a                = 2.000000
%

*** testing is unlikely to make it
***   (x+a)-(x-a) <> 2a with double+float
%

% cat -n double-float2-c.c
     1 /* double-float2.c */
     2 #include <stdio.h>
     3 int main () {
     4 double x; float a, y, z, r1, r2;
     5 a = 1.0;
     6 x = 1125899973951487.0;
     7 y = (x + a);
     8 z = (x - a);
     9 r1 = y - z;
    10 r2 = 2 * a;
    11 printf("(x + a) - (x - a) = %f\n", r1);
    12 printf("2a                = %f\n", r2);
    13 }
%

*** only one digit difference:

% diff double-float2-c.c double-float-c.c
1c1
< /* double-float2.c */
---
```

```
> /* double-float.c */
6c6
< x = 1125899973951487.0;
---
> x = 1125899973951488.0;
%

*** compilation and execution:

% gcc double-float2-c.c
% ./a.out
(x + a) - (x - a) = 0.000000
2a                = 2.000000
%

***********************************************
* Astree takes rounding errors into account... *
***********************************************
%

*** example ((x+a)-(x-a) = 2a in double+double):
%

% cat -n double-double.c
     1 /* double-double.c */
     2 int main () {
     3 double x; double a, y, z, r1, r2;
     4 a = 1.0;
     5 x = 1125899973951488.0;
     6 y = (x + a);
     7 z = (x - a);
     8 r1 = y - z;
     9 r2 = 2 * a;
    10 __ASTREE_log_vars((r1, r2));
    11 }
%

*** static analysis by Astree:

% astree --exec-fn main --print-float-digits 10 double-double.c \
  |& egrep "(launched)|(r2 in )|(r1 in)"

direct = <float-interval: r2 in {2.}, r1 in {2.} >
%

*** example ((x+a)-(x-a) <> 2a in double+float):
%

% cat -n double-float.c
     1 /* double-float-analyze.c */
     2 int main () {
     3 double x; float a, y, z, r1, r2;
     4 a = 1.0;
     5 x = 1125899973951488.0;
     6 y = (x + a);
     7 z = (x - a);
     8 r1 = y - z;
     9 r2 = 2 * a;
    10 __ASTREE_log_vars((r1, r2));
    11 }
%

*** static analysis by Astree:

% astree --exec-fn main --print-float-digits 10 double-float.c \
  |& egrep "(launched)|(r2 in )|(r1 in)"

direct = <float-interval: r2 in {2.}, r1 in [-134217728., 134217728.] >
%

*** Note that Astree takes to worst case among all possible
*** roundings (towards +oo, -oo, 0 or closest).
%

*******************************************************
* Astree takes into account the potential accumulation *
* of rounding errors over very long periods of time... *
*******************************************************
%

*** example 1:

% cat -n rounding-c.c
     1 #include <stdio.h>
     2 int main () {
     3  int i; double x; x = 0.0;
     4  for (i=1; i<=1000000000; i++) {
     5   x = x + 1.0/10.0;
     6  }
     7 printf("x = %f\n", x);
     8 }
%

*** compilation and execution (a few seconds):

% gcc rounding-c.c
% time ./a.out
x = 99999998.745418
3.476u 0.008s 0:03.48 99.7% 0+0k 0+0io 0pf+0w
%

*** We do not find 100000000 since 1.0/10.0
*** is 0.0001100110011001100... in base 2
%

*** static analysis with Astree:

% cat -n rounding.c
     1 int main () {
     2  double x; x = 0.0;
     3  while (1) {
     4   x = x + 1.0/10.0;
     5   __ASTREE_log_vars((x));
     6   __ASTREE_wait_for_clock(());
     7  }
     8 }
%

% cat rounding.config
 __ASTREE_max_clock((1000000000));
%

% astree --exec-fn main --config-sem rounding.config --unroll 0 rounding.c\
 |& egrep "(x in)|(\|x\|)|(WARN)" | tail -2
direct = <float-interval: x in [0.1, 2.0000005e+08] >
  |x| <= 1.0000001*((0. + 0.10000001/(1.0000001-1))*(1.0000001)^clock - 0.10000001/(1.0000001-1)) + 0.10000001 <= 2.0000005e+08
%
*** Note that example 1 is at the origin of the
*** Patriot missile failure on Feb. 25th, 1991
%

*** example 2:

% cat -n bary.c
     1 /* bary.c */
     2 typedef enum {FALSE = 0, TRUE = 1} BOOLEAN;
     3 float INIT,C1,I;
     4 float RANDOM_INPUT;
     5 __ASTREE_volatile_input((RANDOM_INPUT [-1.,1.]));
     6
     7 void bary () {
```

```
     8   static float X,Y,Z;
     9   if (C1>0.)
    10     {Z = Y;Y = X;}
    11   if (INIT>0.)
    12     {
    13       X=I;
    14       Y=I;
    15       Z=I;
    16     }
    17   else
    18     {X = 0.50000001 * X + 0.30000001*Y + 0.20000001*Z  ;};
    19   __ASTREE_log_vars((X,Y,Z));
    20
    21 }
    22
    23 void main () {
    24  INIT = 1.;
    25   C1 = RANDOM_INPUT;
    26   I  = RANDOM_INPUT;
    27   while (1) {
    28     bary();
    29     INIT = RANDOM_INPUT;
    30     C1 = RANDOM_INPUT;
    31     I  = RANDOM_INPUT;
    32     __ASTREE_wait_for_clock(());
    33  }
    34 }
%

*** configuration file (10 hours at 1/100th s):

% cat -n bary10.config
     1 __ASTREE_max_clock((3600000));
%

*** static analysis by Astree:

% astree --exec-fn main --config-sem bary10.config bary.c \
 |& tail -n 50 | egrep --after-context 1 "(launched)|(<float-interval: Z in)"
  <float-interval: Z in [-1.7111293, 1.7111294],
%

*** configuration file (100 hours at 1/100th s):

% cat -n bary100.config
     1 __ASTREE_max_clock((36000000));
%

*** static analysis by Astree:

% astree --exec-fn main --config-sem bary100.config bary.c \
 |& tail -n 50 | egrep --after-context 1 "(launched)|(<Z in)"
  <float-interval: Z in [-215.19279, 215.1928], Y in [-215.19279, 215.1928],
%

*** configuration file (1000 hours at 1/100th s):

% cat -n bary1000.config
     1 __ASTREE_max_clock((360000000));
%

*** static analysis by Astree:

% astree --exec-fn main --config-sem bary1000.config bary.c \
 |& tail -n 50 | egrep --after-context 1 "(launched)|(<Z in)"
  <float-interval: Z in [-2.1294954e+23, 2.1294955e+23],
%
*** (note that the analysis time is independent
***  of the execution time.)
%
```

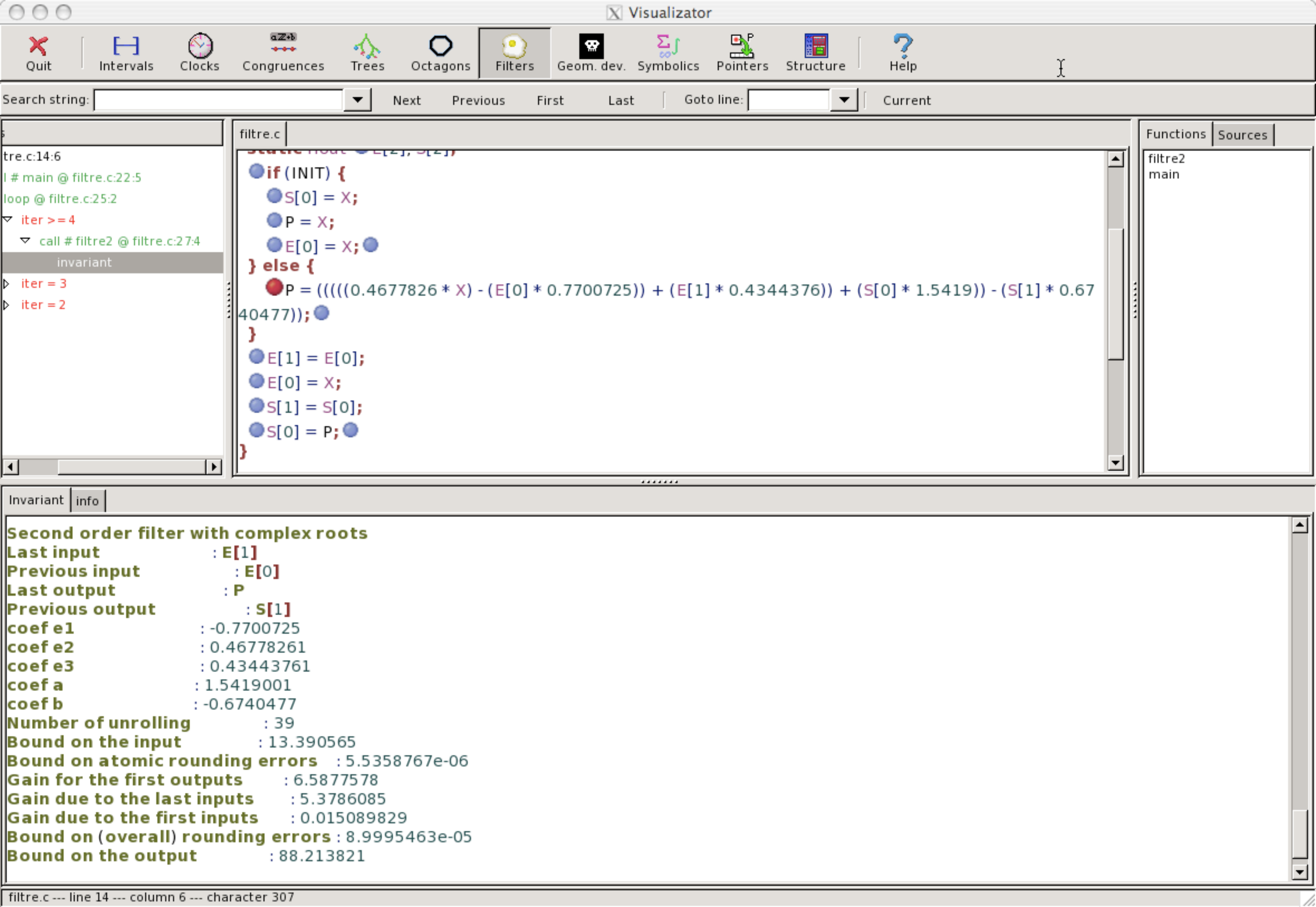
```
*****************************************************
* Astree knows about truncated float computations... *
*****************************************************
%

*** example (truncated computations):

% cat -n moda_dur_3.c
     1 /* entree */
     2 double X;
     3 __ASTREE_volatile_input((X [-186.,186.]));
     4
     5 /* sortie */
     6 double RESULTAT;
     7
     8 void N()
     9 {
    10   int tronc_entier;
    11   double entree,diametre,min,rapport,troncature,plancher,multiple_inf,reste,reste_abs,multiple_sup,plus_proche;
    12   int BPO;
    13   min = 0;
    14   diametre = 1.;
    15
    16   /* au choix: nouvelle entree ou retroaction */
    17   if (BPO) entree = X;
    18   else     entree = RESULTAT;
    19
    20   /* calcul du rapport de entree - min / diametre, puis de sa troncature */
    21   min = 0;
    22   diametre = 1.;
    23   rapport = (entree - min) / diametre;
    24   tronc_entier = (int) rapport;
    25   troncature = (double) tronc_entier;
    26
    27   /* calcul de la valeur plancher de ce rapport */
    28   if (rapport<0) plancher = troncature - 1;
    29   else           plancher = troncature;
    30
    31   /* calcul du reste de l'entree */
    32   reste = entree - (diametre * plancher);
    33
    34   /* calcul du multiple inferieur a l'entree*/
    35   multiple_inf = entree - reste;
    36
    37   /* calcul du multiple superieur a l'entree*/
    38   multiple_sup = multiple_inf + diametre;
    39
    40
    41   /* calcul du multiple le plus proche */
    42   if (reste < 0) reste_abs = -reste;
    43   else           reste_abs = reste;
    44   if (reste_abs <= 0.5*diametre)  plus_proche = multiple_inf;
    45   else                            plus_proche = multiple_sup;
    46
    47
    48   /* resultat */
    49   RESULTAT = plus_proche;
    50    __ASTREE_log_vars((entree,RESULTAT;mod,inter));
    51 }
    52
    53
    54 void main()
    55 {
    56   while (1) {
    57     N();
    58     __ASTREE_wait_for_clock(());
    59   }
    60 }
%
```

```

*** static analysis by Astree (1 - **WITHOUT**
*** abstract domain for modulo arithmetics):

% astree moda_dur_3.c --exec-fn main --no-mod \
 |& egrep "(launched)|(<float-interval)|(WARN)" |& tail -n 1
  <float-interval: entree in [-18328581., 19048581.],
%

*** static analysis by Astree (2 - **WITH**
*** abstract domain for modulo arithmetics):

% astree moda_dur_3.c --exec-fn main --mod \
 |& egrep "(launched)|(<float-interval)|(WARN)" |& tail -n 1
  <float-interval: entree in [-186.09999, 186.10001],
%

*** troncation information derived by Astree:

% astree moda_dur_3.c --exec-fn main --mod \
 |& egrep --after-context 18 "(launched)|(WARN)|(direct =)" | tail -n 18
  <float-interval: entree in [-186.09999, 186.10001],
   RESULTAT in [-186.09999, 186.10001] >
  <modulo:
    there exists an integer i in ((entree) - 0.)/1. + [-0.5;0.50000001]
such that: RESULTAT = 1.*.i + [-3.3328896e-13;3.3328896e-13]
>
  <modulo:
    tronc_entier = Arr_0(((entree) - 0.)/1. + [0.;0.]) + [-0.;0.]
there exists an integer i in ((entree) - 0.)/1. + [-0.5;0.50000001]
such that: plus_proche = 1.*.i + [-3.3328896e-13;3.3328896e-13]
there exists an integer i in ((entree) - 0.)/1. + [-1.;8.2645002e-14]
such that: reste=entree - 1.*i + [-1.6600055e-13;1.6600055e-13]
there exists an integer i in ((entree) - 0.)/1. + [-1.;8.2645002e-14]
such that: plancher = i + [-4.1633364e-14;4.1633364e-14]
troncature = Arr_0(((entree) - 0.)/1. + [0.;0.]) + [-0.;0.]
rapport=((entree) - 0.)/1. + [-8.2645002e-14;8.2645002e-14]
there exists an integer i in ((entree) - 0.)/1. + [-0.5;0.50000001]
such that: RESULTAT = 1.*.i + [-3.3328896e-13;3.3328896e-13]
%

*************************************************
* Astree knows about synchronous programming... *
*************************************************
%

*** incorrect example:

% cat -n clock-error.c
     1 /* clock-error.c */
     2 int R, T, n = 10;
     3 void main()
     4 { volatile int I;
     5   R = 0;
     6   while (1) {
     7     if (I)
     8       { R = R+1; }
     9     else
    10       { R = 0; }
    11     T = (R>=n);
    12 /*  __ASTREE_wait_for_clock(()); */
    13 }}
%

*** configuration file:

% cat -n clock-error.config
     1 /* clock-error.config */
     2 __ASTREE_volatile_input((I [0,1]));
%

```

```
*** analysis of the incorrect example by Astree:

% astree --exec-fn main --config-sem clock-error.config clock-error.c |& egrep "(launched)|(WARN)"

clock-error.c:8.12-15::[call#main@3:loop@6>=4:]: WARN: signed int arithmetic range [-2147483647, 2147483648] not included in [-2147483648, 2147483647]
%

*** correct example:

% cat -n clock.c
     1 /* clock.c */
     2 int R, T, n = 10;
     3 void main()
     4 { volatile int I;
     5   R = 0;
     6   while (1) {
     7     if (I)
     8       { R = R+1; }
     9     else
    10       { R = 0; }
    11     T = (R>=n);
    12     __ASTREE_wait_for_clock(());
    13 }}
%

*** correction (difference with the incorrect program):

% diff clock-error.c clock.c
1c1
< /* clock-error.c */
---
> /* clock.c */
12c12
< /*  __ASTREE_wait_for_clock(()); */
---
>     __ASTREE_wait_for_clock(());
%

*** configuration file:

% cat -n clock.config
     1 /* clock.config */
     2 __ASTREE_volatile_input((I [0,1]));
     3 __ASTREE_max_clock((3600000));
%

*** analysis of the correct example by Astree:

% astree --exec-fn main --config-sem clock.config clock.c |& egrep "(launched)|(WARN)"

%

***********************************************
* Astree knows about control/command theory... *
***********************************************
%

*** filter example:

% cat -n filtre.c
     1 typedef enum {FALSE = 0, TRUE = 1} BOOLEAN;
     2 BOOLEAN INIT;
     3 float P, X;
     4 volatile float RANDOM_INPUT;
     5 __ASTREE_volatile_input((RANDOM_INPUT [-10.0,10.0]));
     6
     7 void filtre2 () {
     8   static float E[2], S[2];
     9   if (INIT) {
```

```
    10       S[0] = X;
    11       P = X;
    12       E[0] = X;
    13   } else {
    14       P = (((((0.4677826 * X) - (E[0] * 0.7700725)) + (E[1] * 0.4344376)) + (S[0] * 1.5419)) - (S[1] * 0.6740477));
    15   }
    16   E[1] = E[0];
    17   E[0] = X;
    18   S[1] = S[0];
    19   S[0] = P;
    20 }
    21
    22 void main () {
    23   X = RANDOM_INPUT;
    24   INIT = TRUE;
    25   while (TRUE) {
    26   X = RANDOM_INPUT;
    27     filtre2 ();
    28     INIT = FALSE;
    29   }
    30 }
%

*** static analysis by Astree (1 -- WITH 2nd order
*** filter domain):

% astree filtre.c --dump-invariants --exec-fn main |& egrep "(launched)|(WARN)|(P in)"

   X in [-10., 10.], P in [-13.388092, 13.388093],
%

*** static analysis by Astree (2 -- WITHOUT 2nd order
*** filter domain):

% astree filtre.c --exec-fn main --no-filters --dump-invariants |& egrep "(launched)|(WARN)|(P in)"

filtre.c:14.6-114::[call#main@22:loop@25>=4:call#filtre2@27:]: WARN: double->float conversion range [-inf., inf.] not included in [-3.4028234e+38, 3.4028235e+38]
   P in [-3.4028234e+38, 3.4028235e+38], RANDOM_INPUT in [-10., 10.] >
%

**************************************************
* Astree can analyze low level memory operations *
**************************************************
%

*** example 1 (pointer casts):

% cat -n memcpy.c
     1 /* memcpy.c (polymorphic memcpy) */
     2
     3 /* byte per byte copy of src into dst */
     4 void memcpy(char* dst, const char* src, unsigned size)
     5 {
     6   int i;
     7   for (i=0;i<size;i++) dst[i] = src[i];
     8 }
     9
    10 void main()
    11 {
    12   float x = 10.0, y;
    13   int zero = 0;
    14   /* copy of x into y (well-typed) */
    15   memcpy(&y,&x,sizeof(y));
    16   __ASTREE_assert((y==10.0));
    17   /* copy of zero into y (not well-typed but allowed in C) */
    18   memcpy(&y,&zero,sizeof(y));
    19   __ASTREE_assert((y==0.0));
    20 }
```

```
%

*** static analysis by Astree:

% astree --exec-fn main --unroll 5 memcpy.c |& egrep "(launched)|(WARN)"

%

*** example 2 (unions):

% cat -n union.c
     1 /* union.c (union type) */
     2
     3 union {
     4   int type;
     5   struct { int type; int data; } A;
     6   struct { int type; char data[3]; } B;
     7 } u;
     8
     9 void main()
    10 {
    11   /* no assert failure */
    12   u.type = 12;
    13   __ASTREE_assert((u.A.type==12));
    14   __ASTREE_assert((u.B.type==12));
    15
    16   /* assert failure because the modification of u.B.data also modifies u.A.data */
    17   u.A.data = 0;
    18   u.B.data[0] = 12;
    19   __ASTREE_assert((u.A.data==0));
    20 }
%

*** static analysis by Astree:

% astree --exec-fn main --full-memory-model union.c |& egrep "(launched)|(WARN)"

union.c:19.19-30::[call#main@9:]: WARN: assert failure
%


***********************************************
* Astree has a graphic interface under X11... *
***********************************************
%

*** static analysis by Astree

% astree filtre.c --dump-invariants --exec-fn main --export-invariant stat \
  --export-file filtre.inv --export-unroll >& /dev/null
%

*** visualization of the results:
%

% visu --text-size 14 --text-font CMTT filtre.inv >& /dev/null
%

*** (scaling up with GTK+ (library to build graphical
***  user interfaces (GUIs) originally for X Window)!)
%

*********************************************
*** The end, thank you for your attention ***
*********************************************
```



```
static float E[2], S[2];
 if (INIT) {
   S[0] = X;
   P = X;
   E[0] = X;
 } else {
   P = (((((0.4677826 * X) - (E[0] * 0.7700725)) + (E[1] * 0.4344376)) + (S[0] * 1.5419)) - (S[1] * 0.67
40477));
 }
 E[1] = E[0];
 E[0] = X;
 S[1] = S[0];
 S[0] = P;
}
```

```
Second order filter with complex roots
Last input                   : E[1]
Previous input                 : E[0]
Last output                  : P
Previous output                : S[1]
coef e1                 : -0.7700725
coef e2                 : 0.46778261
coef e3                 : 0.43443761
coef a                  : 1.5419001
coef b                  : -0.6740477
Number of unrolling            : 39
Bound on the input             : 13.390565
Bound on atomic rounding errors  : 5.5358767e-06
Gain for the first outputs       : 6.5877578
Gain due to the last inputs       : 5.3786085
Gain due to the first inputs      : 0.015089829
Bound on (overall) rounding errors : 8.9995463e-05
Bound on the output             : 88.213821
```

filtre.c --- line 14 --- column 6 --- character 307