Abstract Interpretation and Application to the Static Analysis of Mission-Critical Embedded Computer Software

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Abstract

Static software analysis has known brilliant successes in the small, by proving complex program properties of programs of a few dozen or hundreds of lines, either by systematic exploration of the state space or by interactive deductive methods. To scale up is a definite problem. Very few static analyzers are able to scale up to millions of lines without sacrificing automation and/or soundness and/or precision. Unsound static analysis may be useful for bug finding but is less useless in safety critical applications where the absence of bugs, at least of some categories of common bugs, should be formally verified.

After recalling the basic principles of abstract interpretation including the notions of abstraction, approximation, soundness, completeness, false alarm, etc., we introduce the domain-specific static analyzer ASTRÃE (www.astree.ens.fr) for proving the absence of runtime errors in mission critical real time embedded synchronous software in the large.

The talk emphasizes soundness (no runtime error is ever omitted), parametrization (the ability to refine abstractions by options and analysis directives), extensibility (the easy incorporation of new abstractions to refine the approximation), precision (few or no false alarms for programs in the considered application domain) and scalability (the analyzer scales to millions of lines).

In conclusion, present-day software engineering methodology, which is based on the control of the design, coding and testing processes should evolve in the near future, to incorporate a systematic control of the final product thanks to domain-specific analyzers that scale up.

1. Classical Examples of Bugs

Classical examples of bugs in integer computations

The factorial program (fact.c)

```
#include <stdio.h>
int fact (int n ) {
  int r, i;
  r = 1;
  for (i=2; i<=n; i++) {
    r = r*i;
  }
  return r;
}
int main() { int n;
  scanf("%d",&n);
  printf("%d!=%d\n",n,fact(n));
}
```

$\leftarrow$ $\texttt{fact}(n) = 2 \times 3 \times \cdots \times n$

$\leftarrow$ read n (typed on keyboard)

$\leftarrow$ write $n\,! = \texttt{fact}(n)$

Compilation of the factorial program (fact.c)

```
#include <stdio.h>
int fact (int n ) {
  int r, i;
  r = 1;
  for (i=2; i<=n; i++) {
    r = r*i;
  }
  return r;
}
int main() { int n;
  scanf("%d",&n);
  printf("%d!=%d\n",n,fact(n));
}
```

```
% gcc fact.c -o fact.exec
%
```

Executions of the factorial program (fact.c)

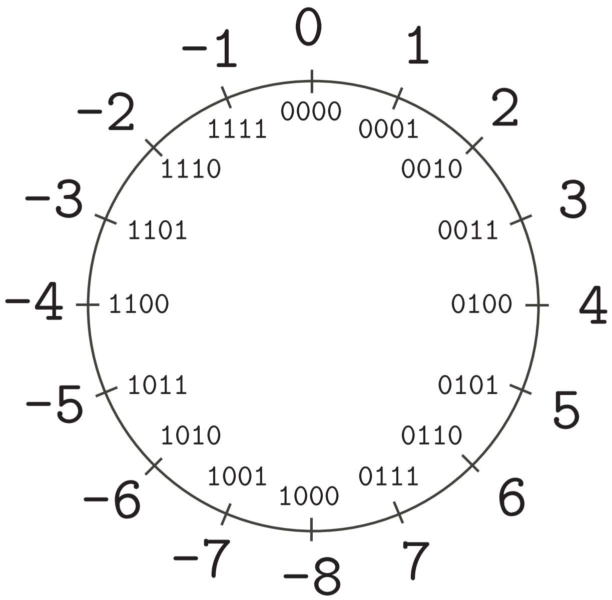
```
#include <stdio.h>
int fact (int n ) {
  int r, i;
  r = 1;
  for (i=2; i<=n; i++) {
    r = r*i;
  }
  return r;
}
int main() { int n;
  scanf("%d",&n);
  printf("%d!=%d\n",n,fact(n));
}
```

```
% gcc fact.c -o fact.exec
% ./fact.exec
3
3!  = 6
% ./fact.exec
4
4!  = 24
% ./fact.exec
100
100!  = 0
% ./fact.exec
20
20!  = -2102132736
```

Bug hunt

– Computers use integer modular arithmetics on n bits (where $n = 16, 32, 64$, etc)

– Example of an integer representation on 4 bits (in *complement to two*) :

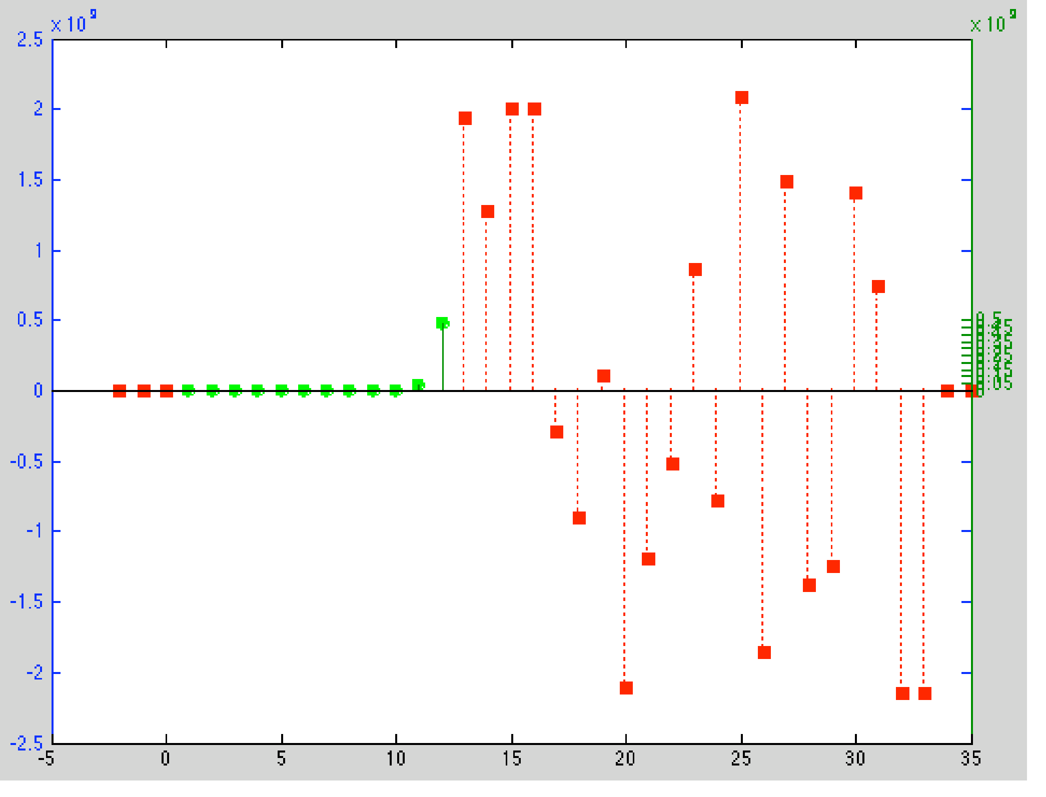


– Only integers between -8 and 7 can be represented on 4 bits

– We get $7 + 2 = -7$
$7 + 9 = 0$

The bug is a failure of the programmer

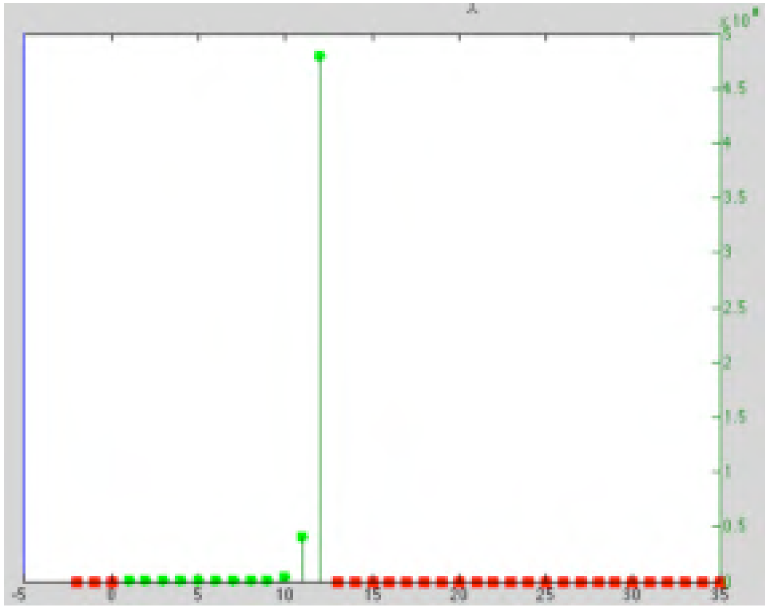
In the computer, the function `fact(n)` coincide with $n! = 2 \times 3 \times \ldots . \times n$ on the integers only for $1 \leqslant n \leqslant 12$:



Proof of absence of runtime error by static analysis

```
% cat -n fact_lim.c
 1 int MAXINT = 2147483647;
 2 int fact (int n) {
 3    int r, i;
 4    if (n < 1) || (n = MAXINT) {
 5        r = 0;
 6    } else {
 7        r = 1;
 8        for (i = 2; i<=n; i++) {
 9            if (r <= (MAXINT / i)) {
10                r = r * i;
11            } else {
12                r = 0;
13            }
14        }
15    }
16    return r;
17 }
18
19 int main() {
20    int n, f;
21    f = fact(n);
22 }
% astree -exec-fn main fact_lim.c |& grep WARN
%
```

→ No alarm!



Examples of classical bugs in floating point computations

Mathematical models and their implementation on computers

– Mathematical models of physical systems use real numbers

– Computer modeling languages (like SCADE) use real numbers

– Real numbers are hard to represent in a computer (π has an infinite number of decimals)

– Computer programming languages (like C or OCAML) use floating point numbers

Floats

– *Floating point numbers* are a finite subset of the *rationals*

– For example one can represent 32 floats on 6 bits, the 16 positive normalized floats spread as follows on the line:

– When real computations do not spot on a float, one must *round the result to a close float*

Example of rounding error (1)

$$(x + a) - (x - a) \neq 2a$$

```
#include <stdio.h>
int main() {
  double x, a; float y, z;
  x = 1125899973951488.0;
  a = 1.0;
  y = (x+a);
  z = (x-a);
  printf("%f\n", y-z);
}
```

```
% gcc arrondi1.c -o arrondi1.exec
% ./arrondi1.exec
134217728.000000
%
```

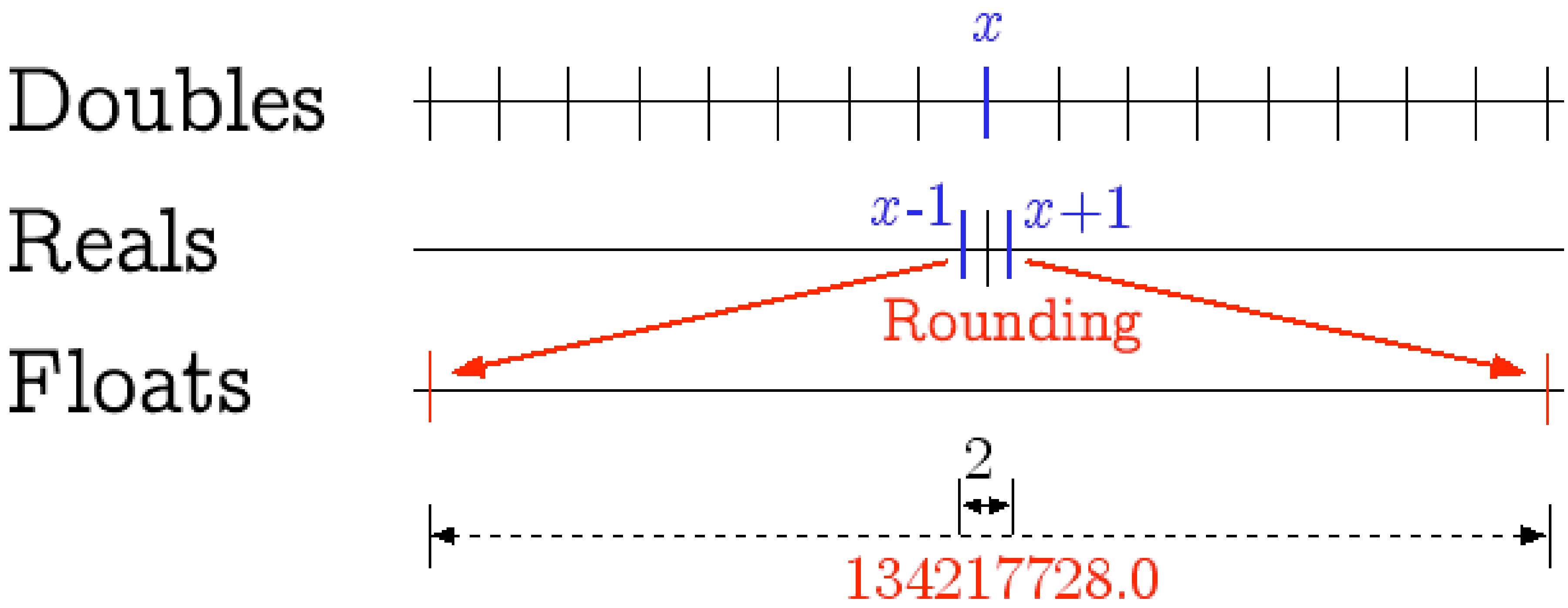
Example of rounding error (2)

$$(x + a) - (x - a) \neq 2a$$

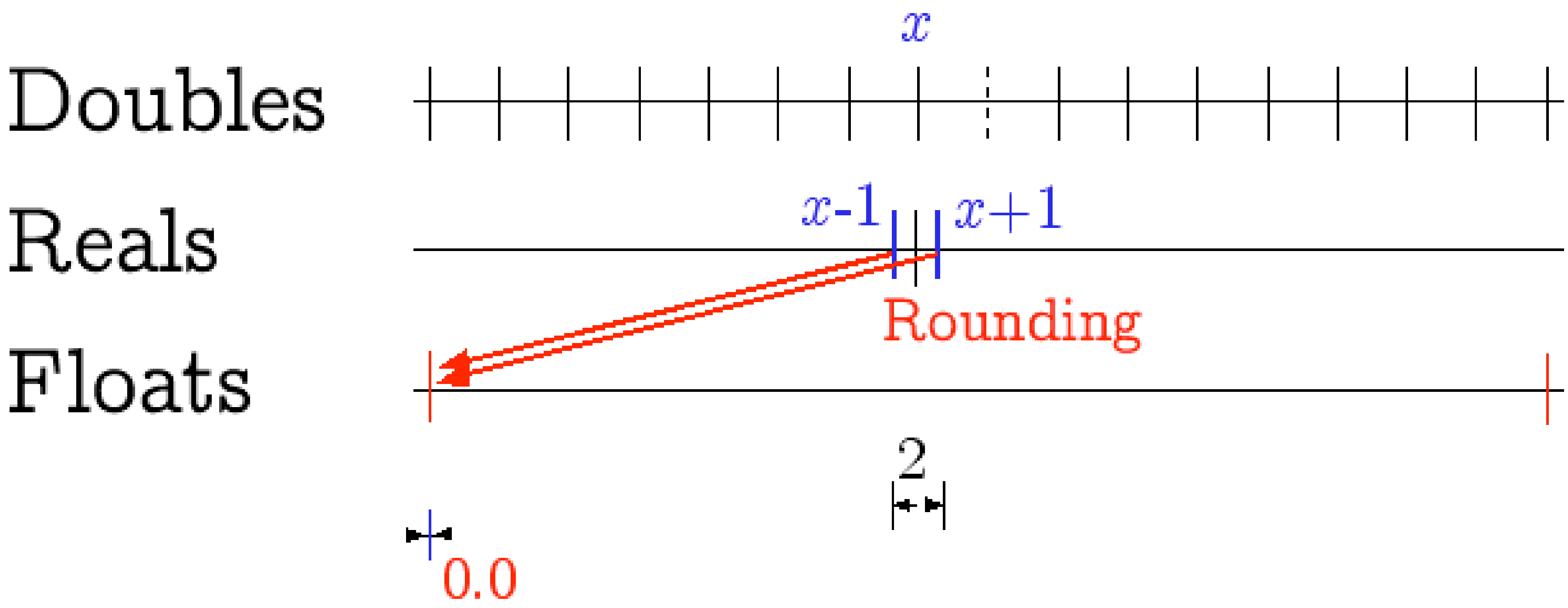
```
#include <stdio.h>
int main() {
  double x, a; float y, z;
  x = 1125899973951487.0;
  a = 1.0;
  y = (x+a);
  z = (x-a);
  printf("%f\n", y-z);
}
```

```
% gcc arrondi2.c -o arrondi2.exec
% ./arrondi2.exec
0.000000
%
```

Bug hunt (1)



Bug hunt (2)

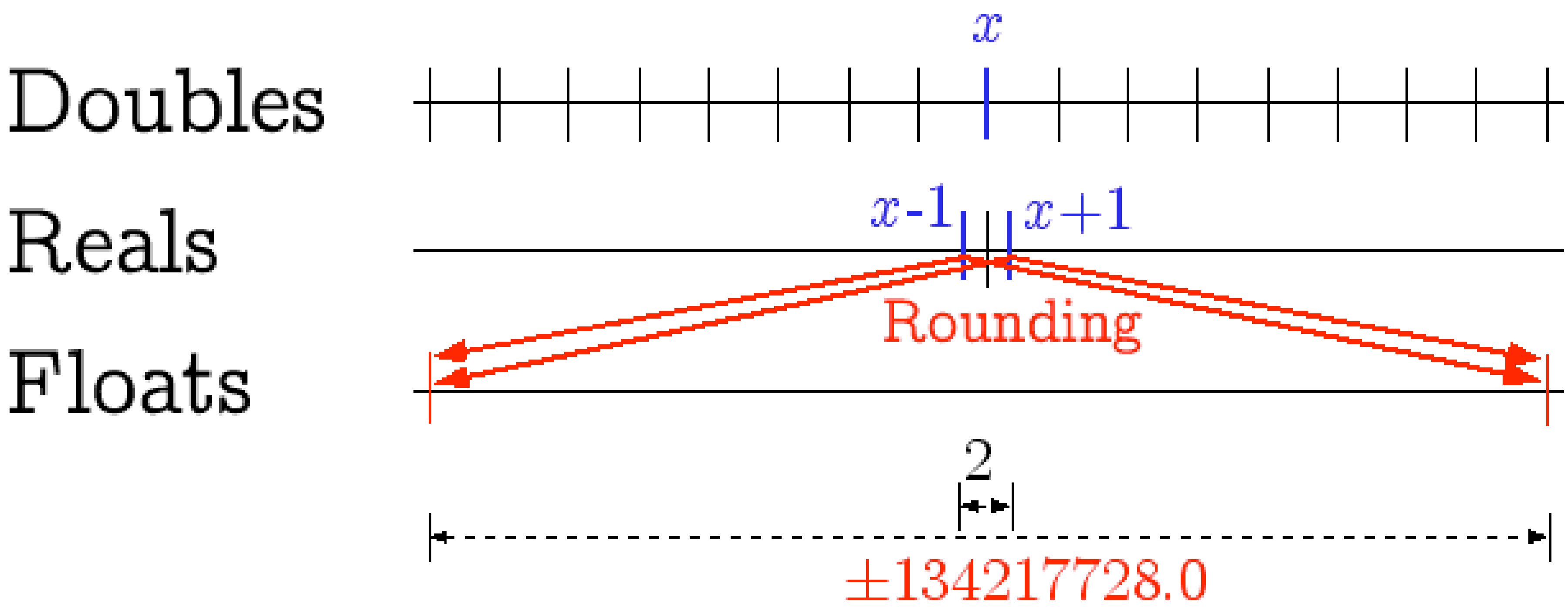


Proof of absence of runtime error by static analysis

```
% cat -n arrondi3.c
     1  int main() {
     2      double x; float y, z, r;;
     3      x = 1125899973951488.0;
     4      y = x + 1;
     5      z = x - 1;
     6      r = y - z;
     7      __ASTREE_log_vars((r));
     8  }
% astree -exec-fn main -print-float-digits 10 arrondi3.c \
  |& grep "r in "
direct = <float-interval: r in [-134217728, 134217728] >[1]
```

[1] ASTRÉE considers the worst rounding case (towards $+\infty$, $-\infty$, 0 or to the nearest) whence the possibility to obtain -134217728.

The verification is done in the worst case



Examples of bugs due to rounding errors

- The patriot missile bug missing Scuds in 1991 because of a software clock incremented by $\frac{1}{10}^{\text{th}}$ of a seconde $((0,1)_{10} = (0,0001100110011001100\ldots)_2$ in binary)
- The Excel 2007 bug : 77.1×850 gives 65,535 but displays as 100,000! (2)

2	65535-2^(-37)	100000	65536-2^(-37)	100001
3	65535-2^(-36)	100000	65536-2^(-36)	100001
4	65535-2^(-35)	100000	65536-2^(-35)	100001
5	65535-2^(-34)	65535	65536-2^(-34)	65536
6	65535-2^(-36)-2^(-37)	100000	65536-2^(-36)-2^(-37)	100001
7	65535-2^(-35)-2^(-37)	100000	65536-2^(-35)-2^(-37)	100001
8	65535-2^(-35)-2^(-36)	100000	65536-2^(-35)-2^(-36)	100001
9	65535-2^(-35)-2^(-36)-2^(-37)	65535	65536-2^(-35)-2^(-36)-2^(-37)	65536

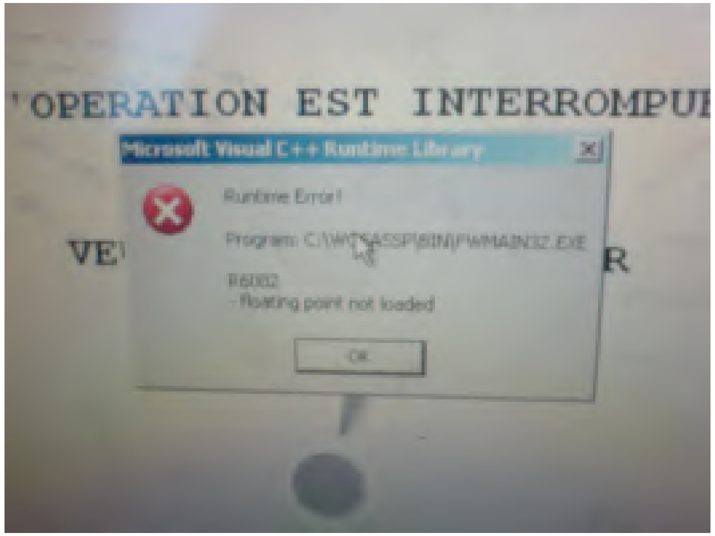
(2) Incorrect float rounding which leads to an alignment error in the conversion table while translating 64 bits IEEE 754 floats into a Unicode character string. The bug appears exactly for six numbers between 65534.99999999995 and 65535 and six between 65535.99999999995 and 65536.

Bugs in the everyday numerical world

Bugs are frequent in everyday life

– Bugs proliferate in banks, cars, telephons, washing machines, ...

– Example (bug in an ATM machine located at 19 Boulevard Sébastopol in Paris, on 21 November 2006 at 8:30):



– Hypothesis (Gordon Moore's law revisited): the number of software bugs in the world doubles every 18 months??? :-(

2. Program verification

Principle of program verification

– Define a semantics of the language (that is the effect of executing programs of the language)

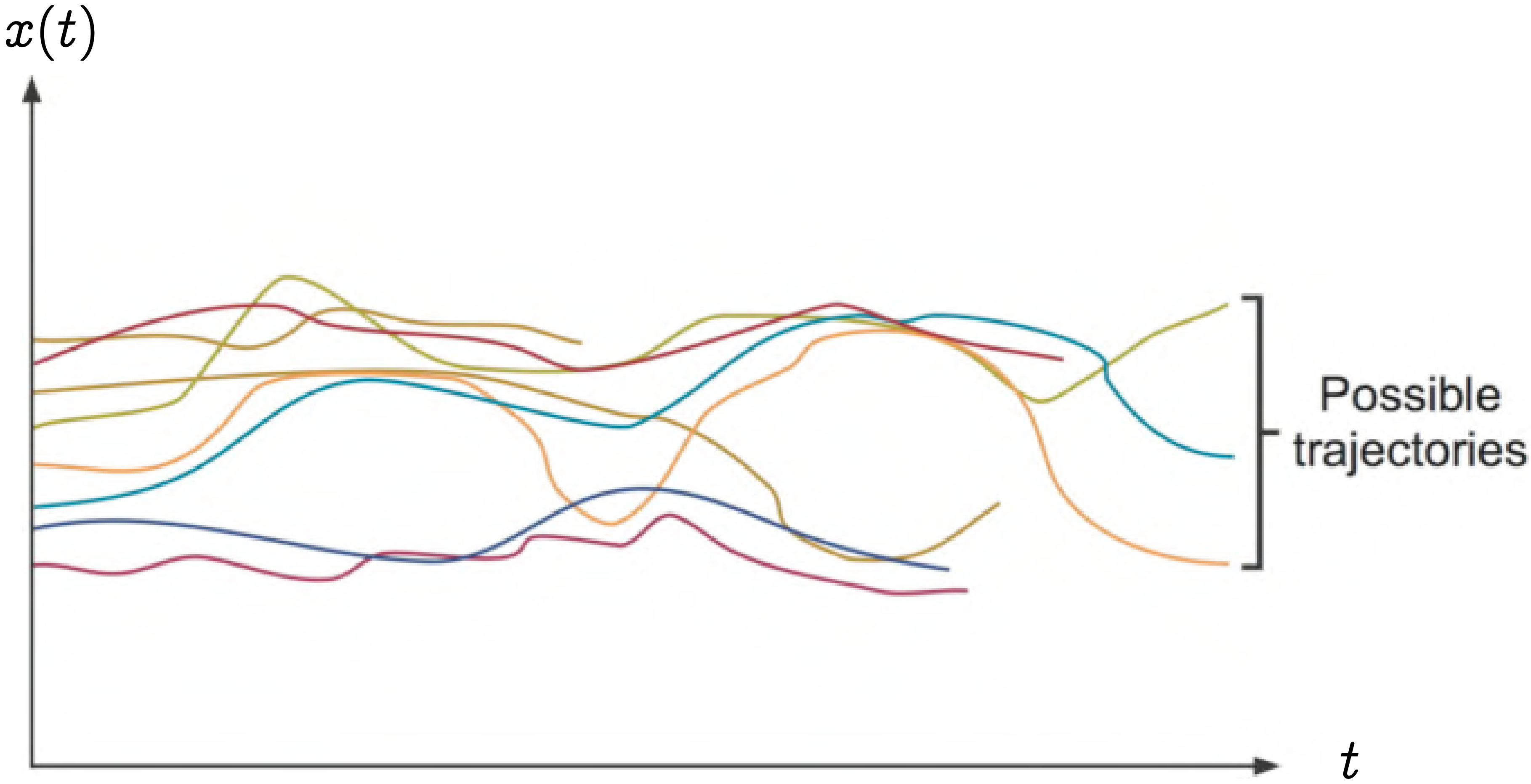
– Define a specification (example: absence of runtime errors such as division by zero, un arithmetic overflow, etc)

– Make a formal proof that the semantics satisfies the specification

– Use a computer to automate the proof

Semantics of programs

Operational semantics of program P



Semantics$[\![P]\!]$

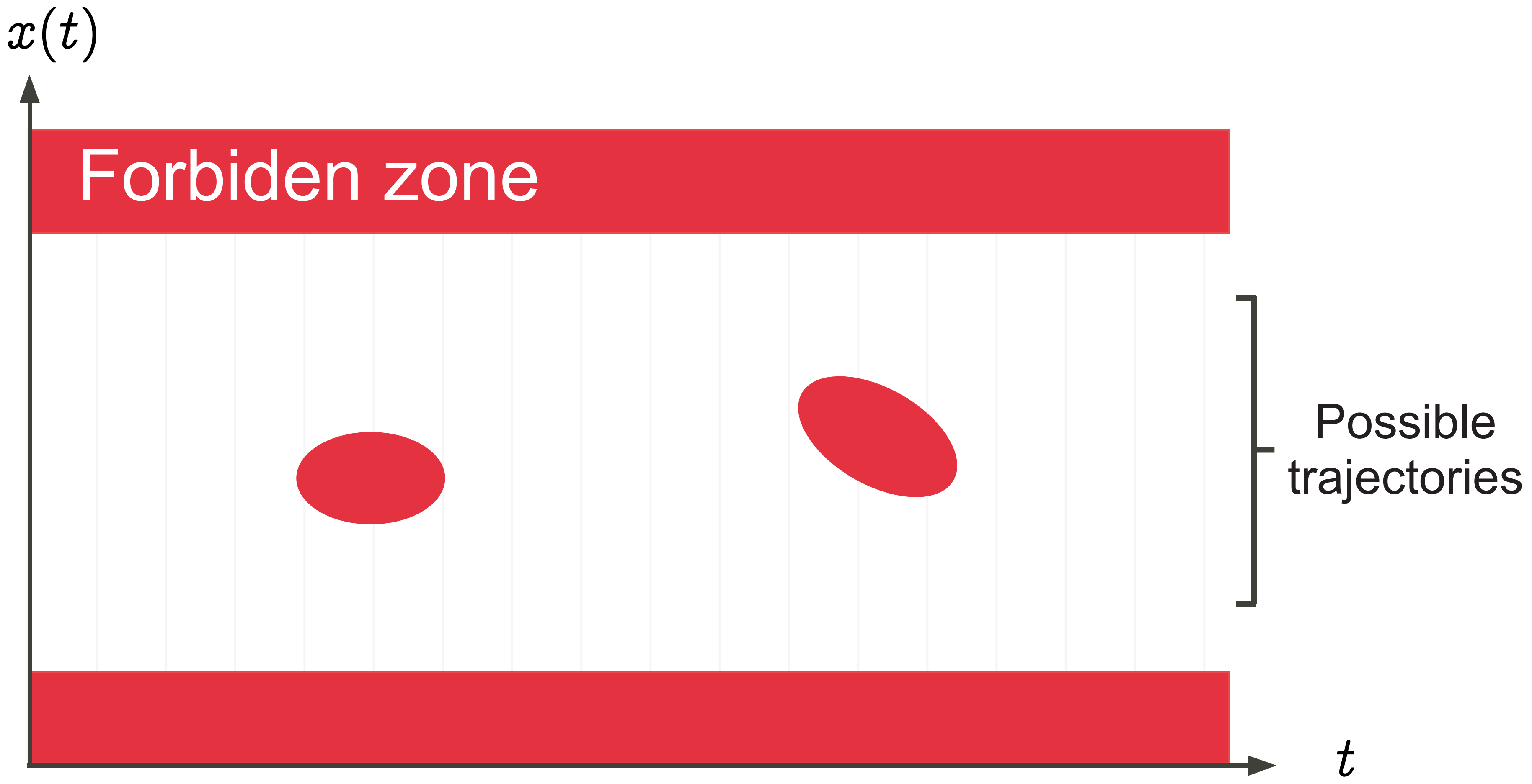
Example: execution trace of `fact(4)`

```
int fact (int n ) {
  int r = 1, i;
  for (i=2; i<=n; i++) {
    r = r*i;
  }
  return r;
}
```

- $\texttt{n} \leftarrow 4; \texttt{r} \leftarrow 1;$
- $\texttt{i} \leftarrow 2; \texttt{r} \leftarrow 1 \times 2 = 1;$
- $\texttt{i} \leftarrow 3; \texttt{r} \leftarrow 2 \times 3 = 6;$
- $\texttt{i} \leftarrow 4; \texttt{r} \leftarrow 6 \times 4 = 24;$
- $\texttt{i} \leftarrow 5;$
- $\texttt{return}\ 24;$

Program specification

Specification of program P



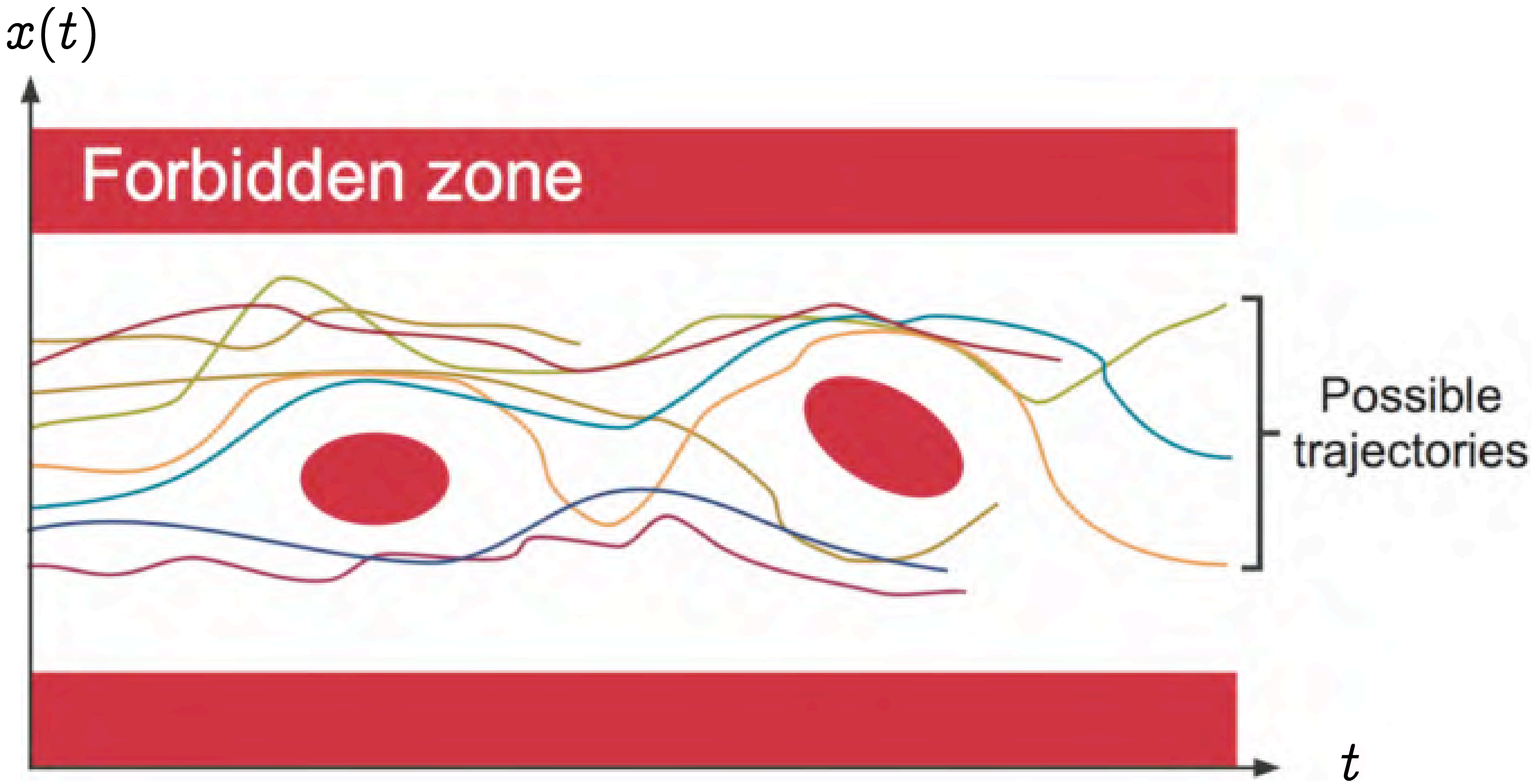
Specification$[\![P]\!]$

Example of specification

```
int fact (int n ) {
  int r, i;
  r = 1;
  for (i=2; i<=n; i++) {     ← no overflow of i++
    r = r*i;                 ← no overflow of r*i
  }
  return r;
}
```

Formal proofs

Formal proof of program P



$$\text{Semantics}[\![P]\!] \subseteq \text{Specification}[\![P]\!]$$

Undecidability and complexity

– The mathematical proof problem is undecidable [3]

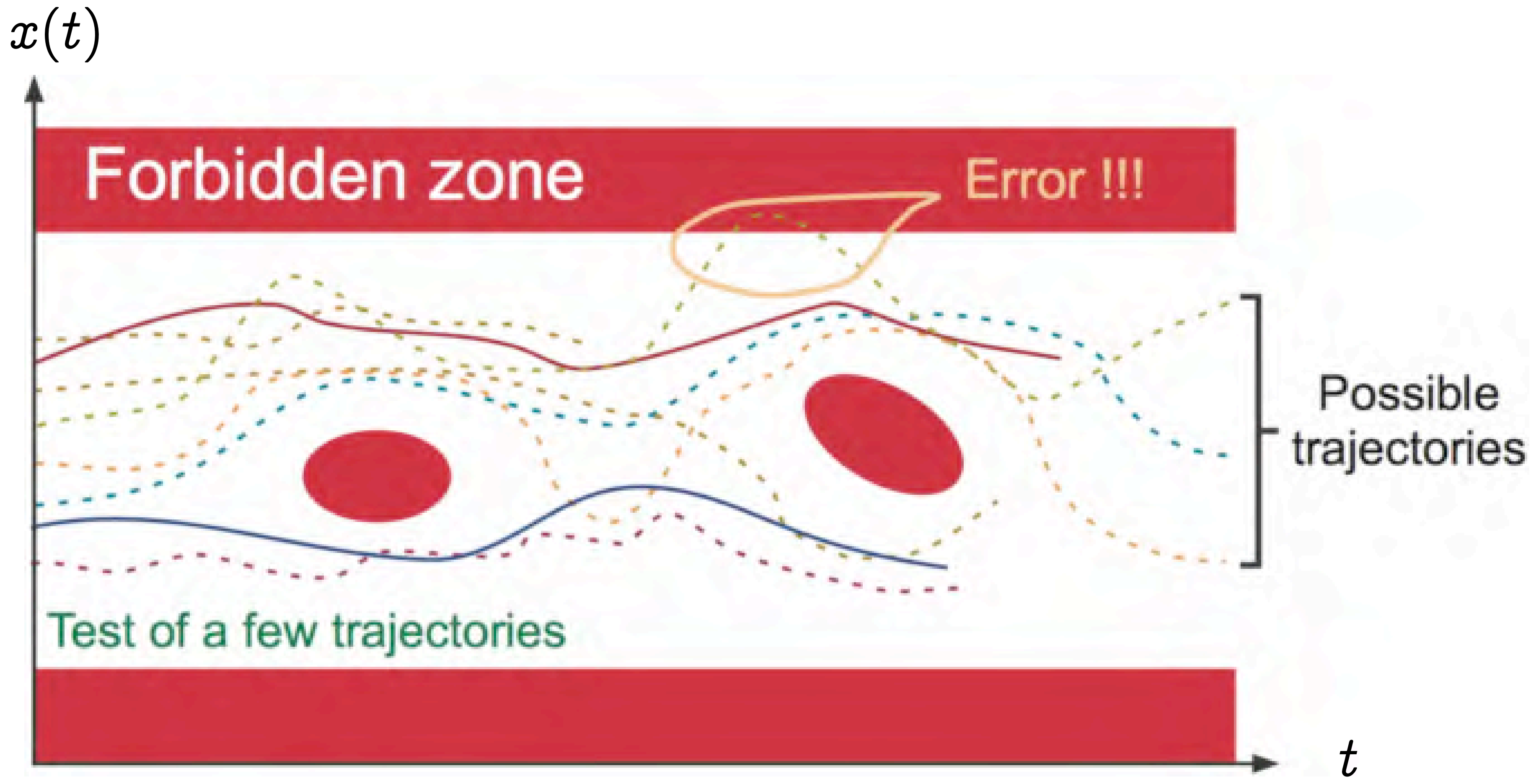
– Even assuming finite states, the complexity is much too high for combinatorial exploration to succeed

– Example: 1.000.000 lines $\times$ 50.000 variables $\times$ 64 bits $\simeq 10^{27}$ states

– Exploring 10^{15} states per seconde, one would need 10^{12} s $>$ 300 centuries (and a lot of memory)!

(3) there are infinitely many programs for which a computer cannot solve them in finite time even with an infinite memory.

Testing is incomplete

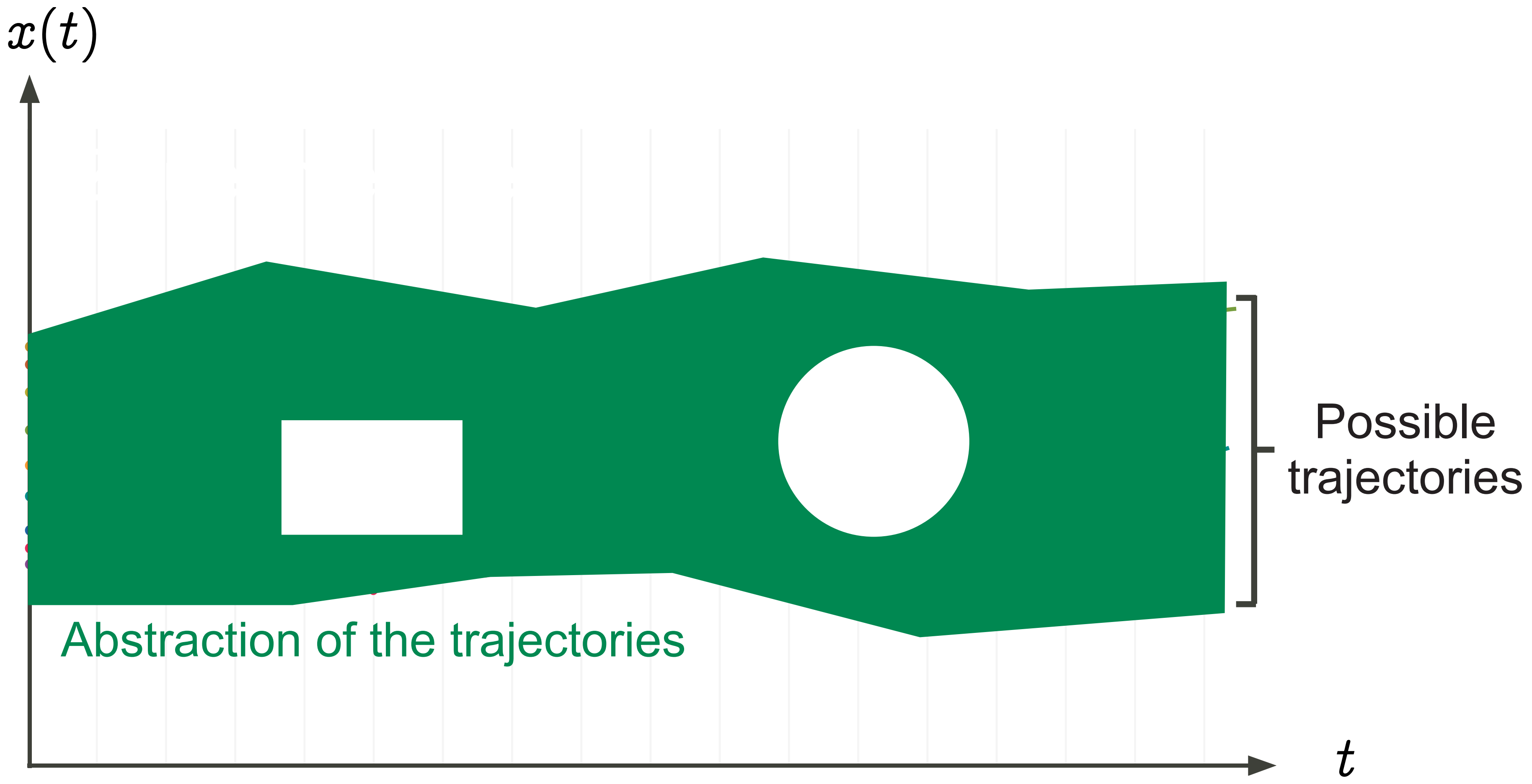


3. Abstract Interpretation [1]

Reference

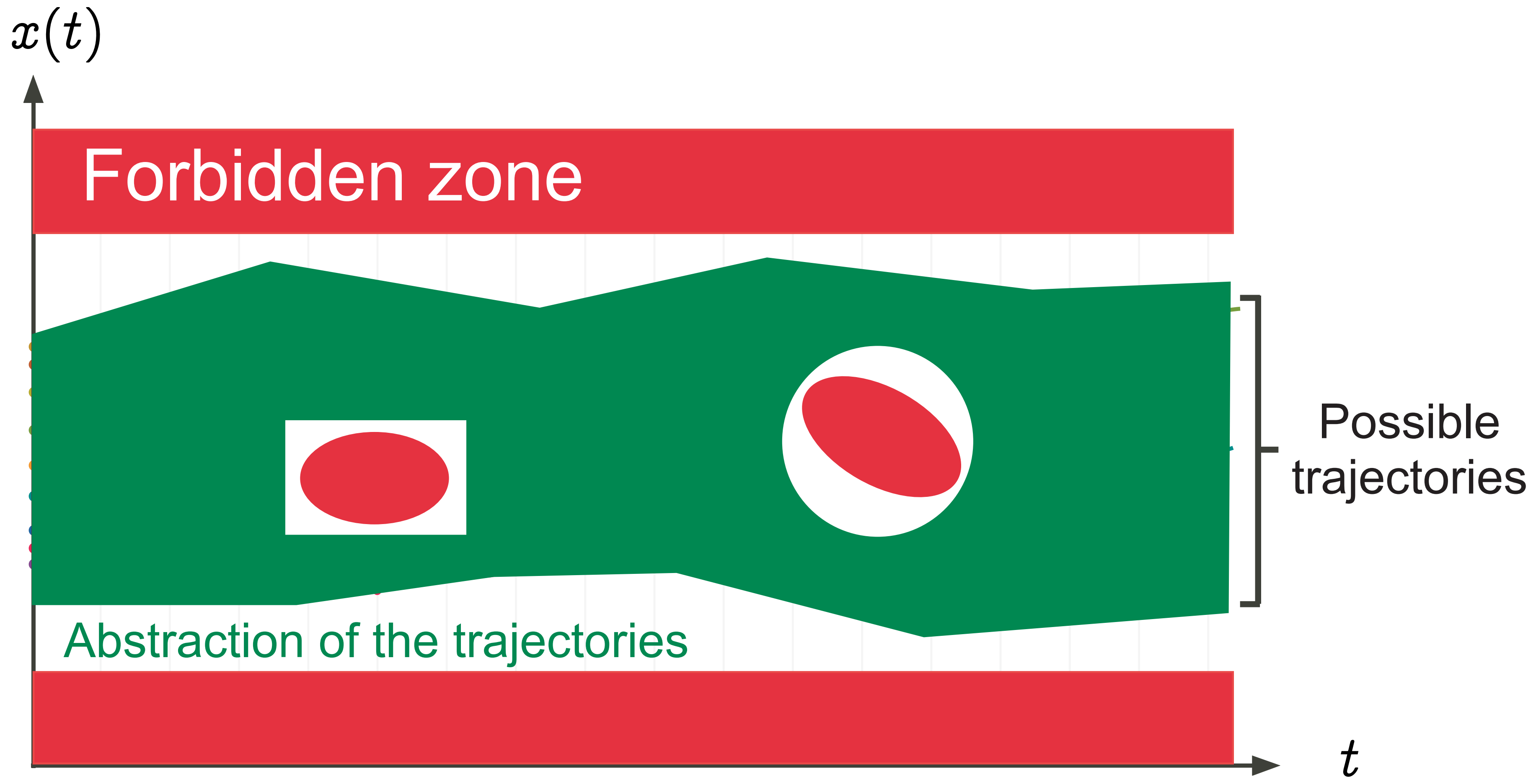
[1] P. Cousot. Méthodes itératives de construction et d'approximation de points fixes d'opérateurs monotones sur un treillis, analyse sémantique de programmes. Thèse d'État ès sciences mathématiques. Université scientifique et médicale de Grenoble. 1978.

Abstraction of program P



Abstraction(Semantics$[\![P]\!]$)

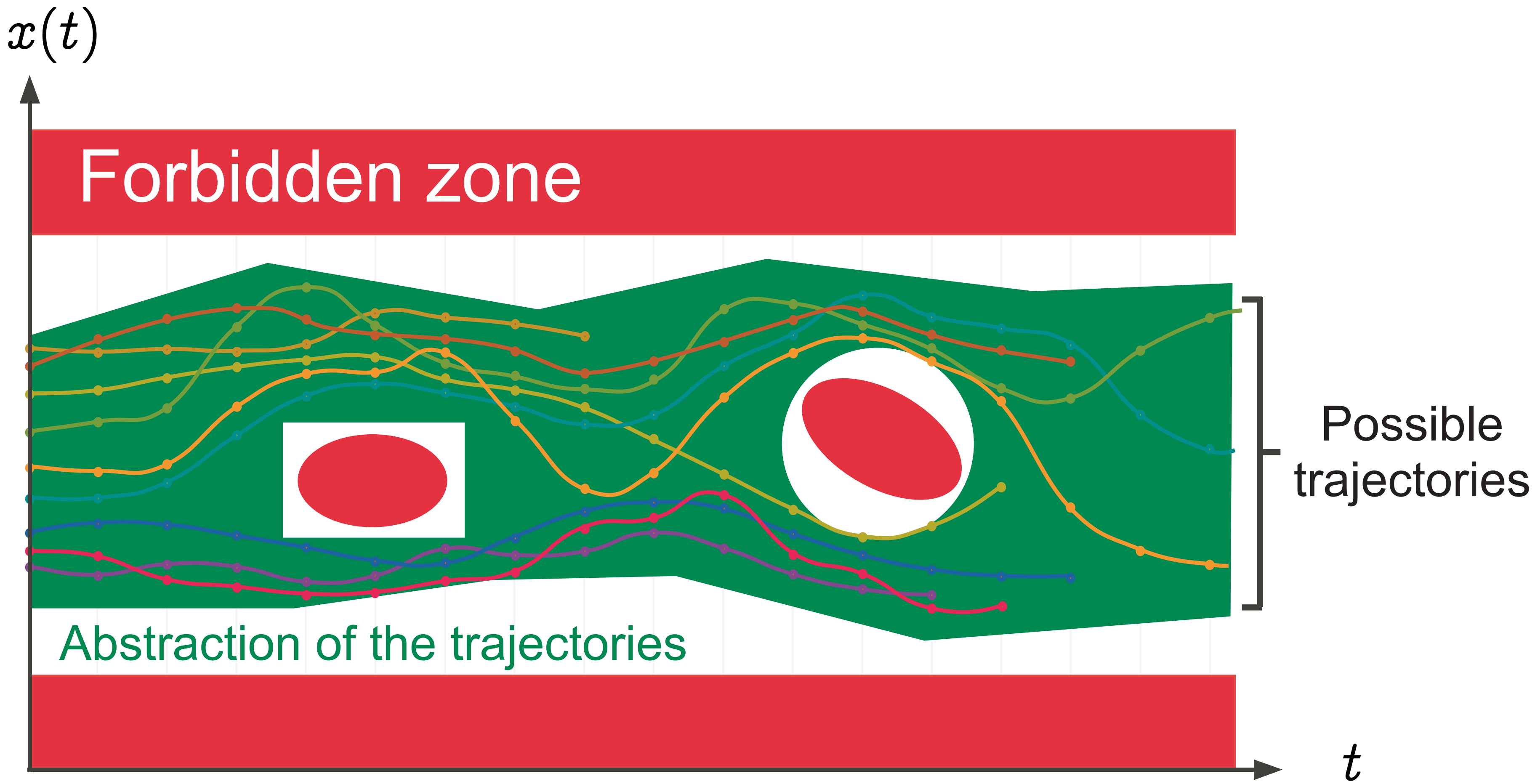
Proof by abstraction



$$\text{Abstraction}(\text{Semantics}[\![P]\!]) \subseteq \text{Specificaton}[\![P]\!]$$

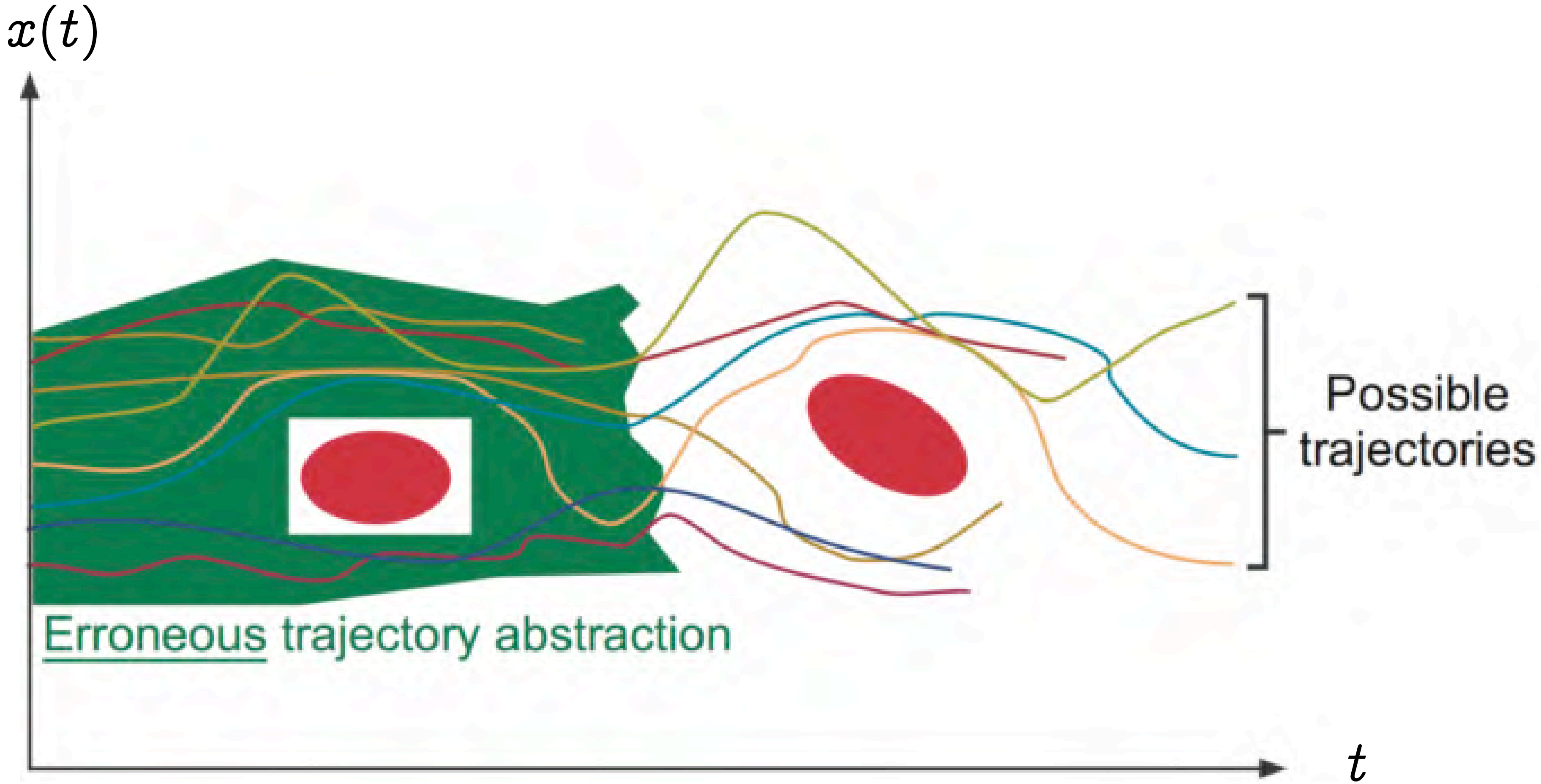
Soundness of abstract interpretation

Abstract interpretation is sound



$$\text{Semantics}[\![P]\!] \subseteq \text{Abstraction}(\text{Semantics}[\![P]\!])$$

Example of unsound abstraction [4]



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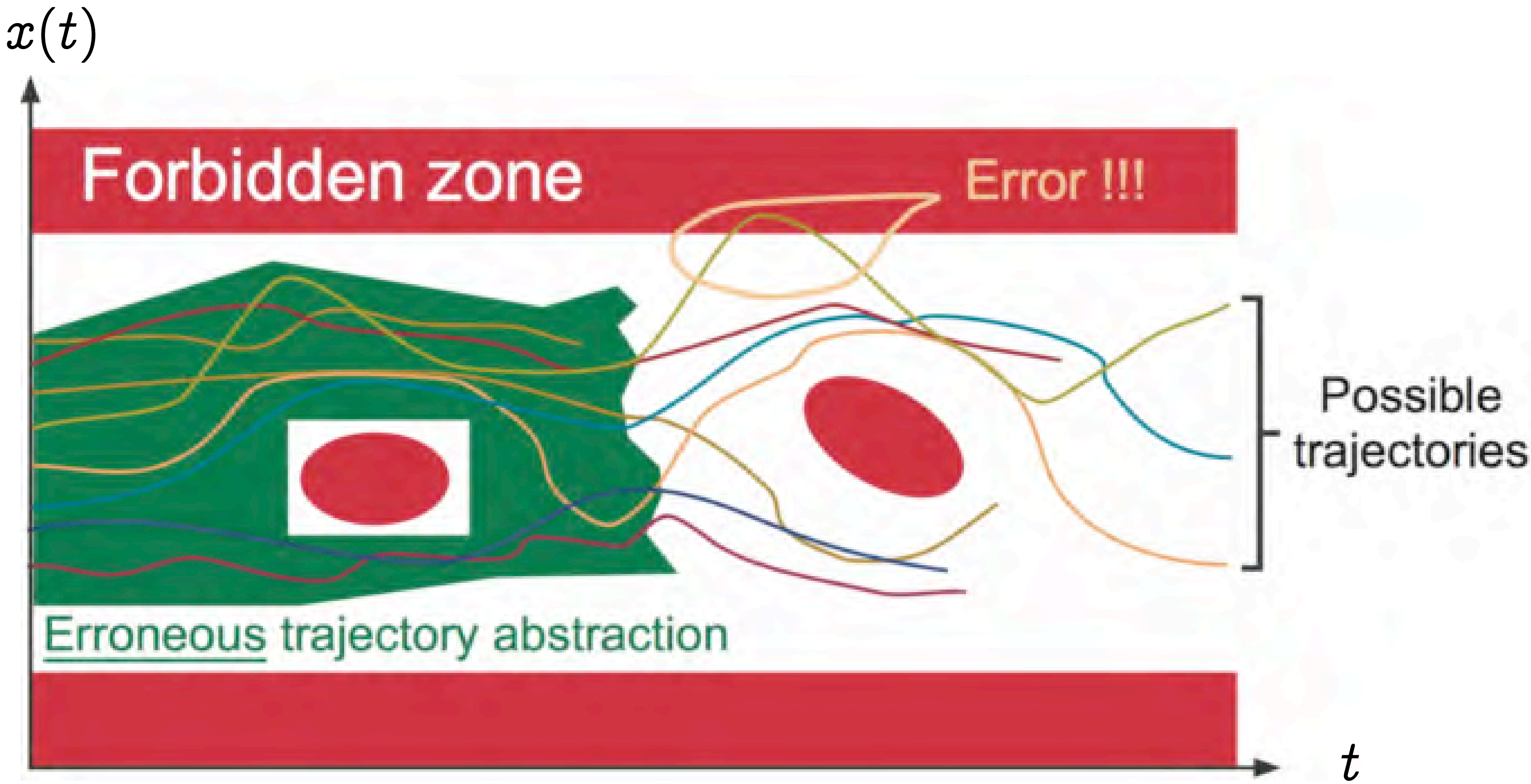
(4) Unsoundness is always excluded by abstract interpretation theory.

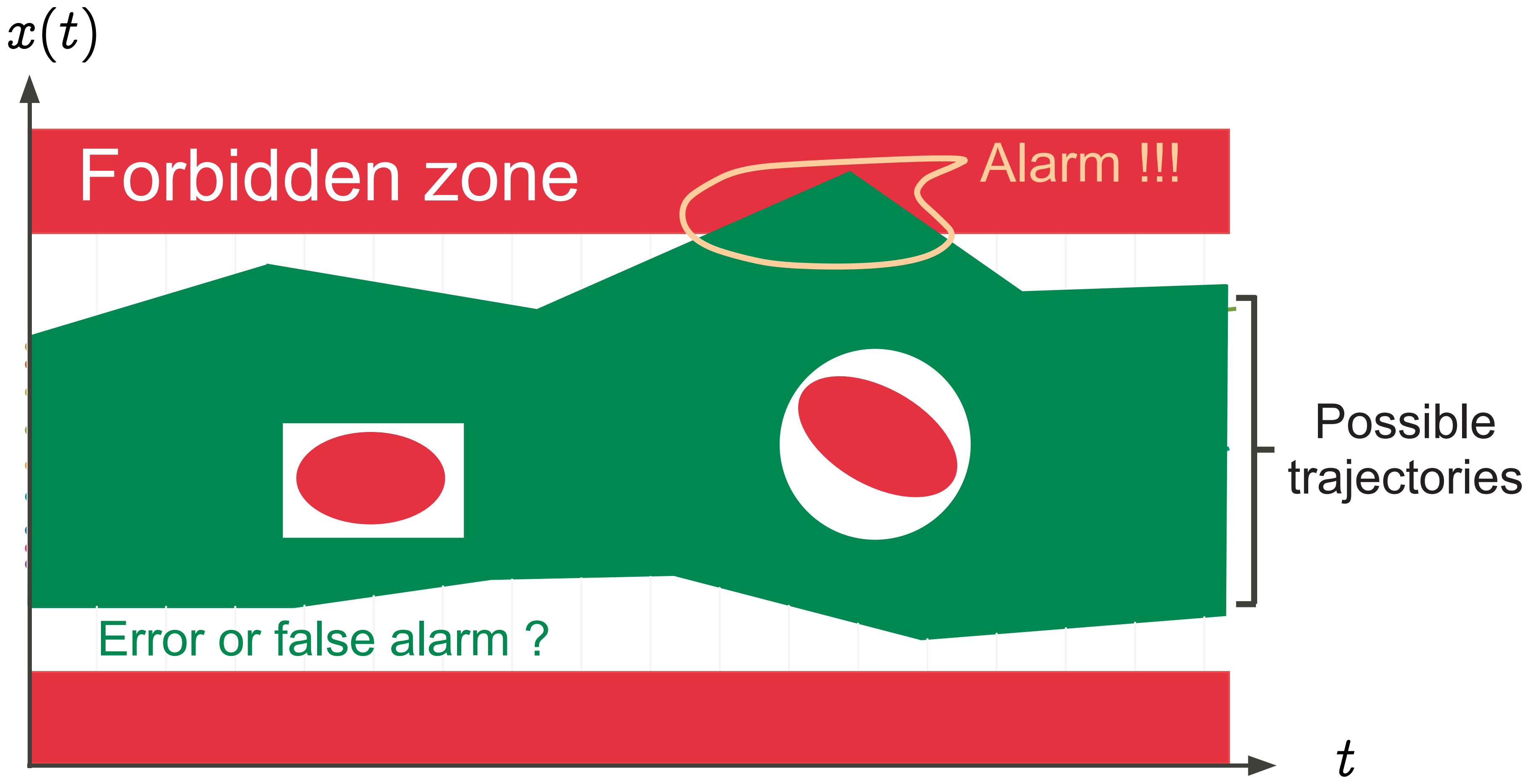
Unsound abstractions are inconclusive (false negatives) (4)



(4) Unsoundness is always excluded by abstract interpretation theory.

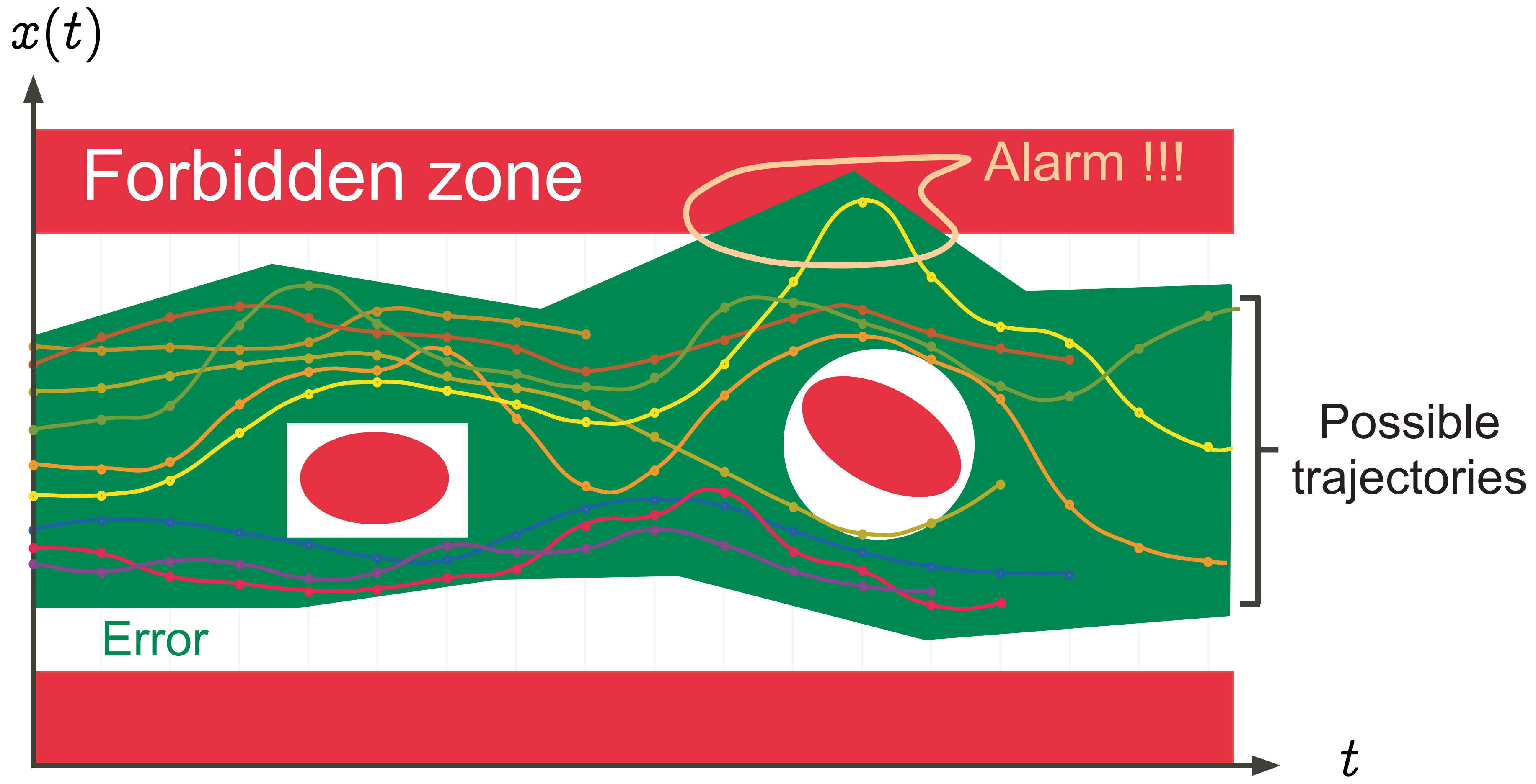
Incompleteness of abstract interpretation

Alarm

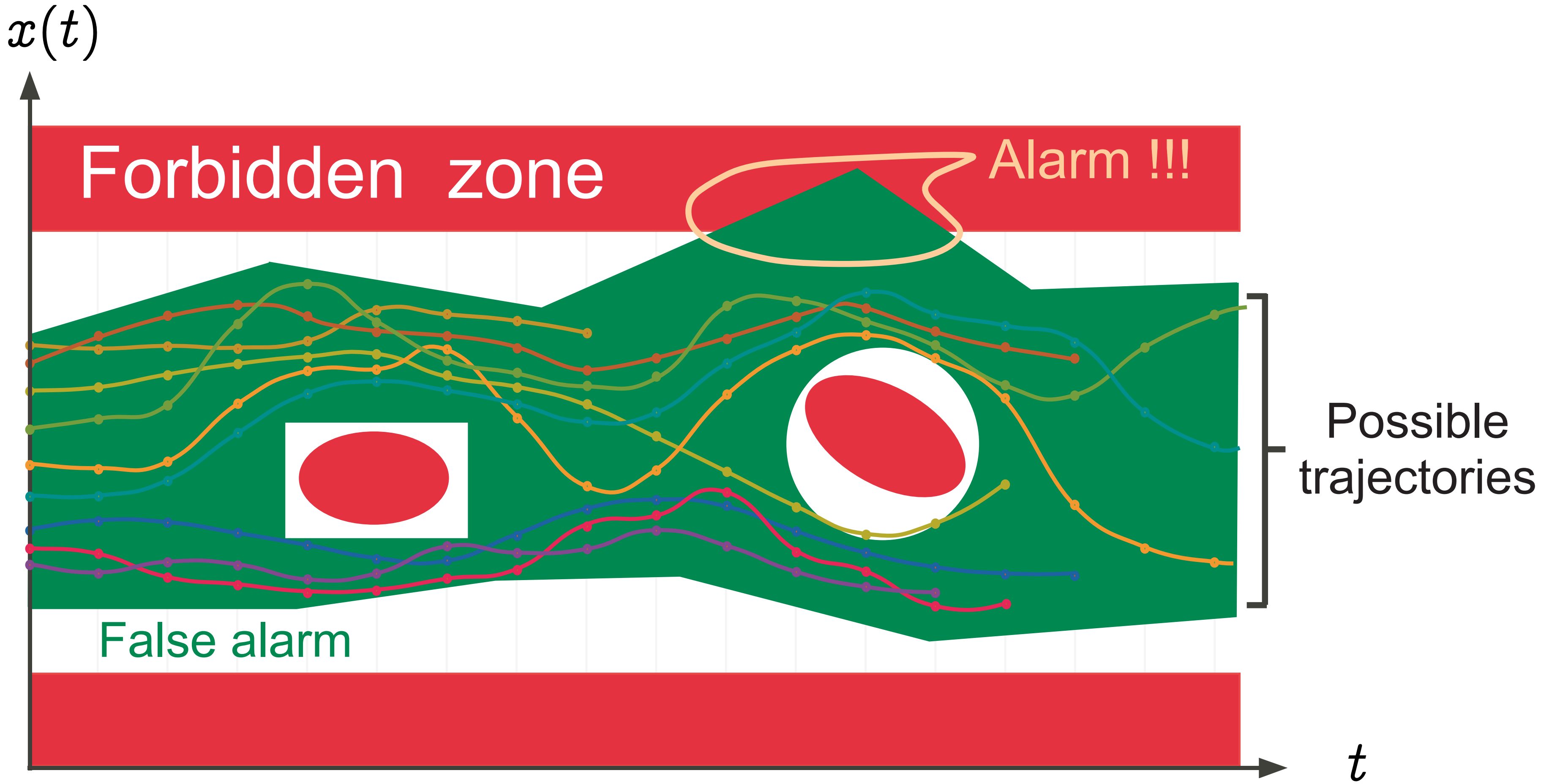


$x(t)$
Forbidden zone
Alarm !!!
Possible trajectories
Error or false alarm ?
t

An alarm can originate from an error



An alarm can originate from an over-approximation



4. Applications of Abstract Interpretation

The Theory of Abstract Interpretation

- A theory of sound approximation of mathematical structures, in particular those involved in the behavior of computer systems
- Systematic derivation of sound methods and algorithms for approximating undecidable or highly complex problems in various areas of computer science
- Main practical application is on the safety and security of complex hardware and software computer systems
- Abstraction: extracting information from a system description that is relevant to proving a property

Applications of Abstract Interpretation

- Static Program Analysis (or Semantics-Checking) [CC77], [CH78], [CC79] including Dataflow Analysis; [CC79], [CC00], Set-based Analysis [CC95], Predicate Abstraction [Cou03], ...
- Grammar Analysis and Parsing [CC03];
- Hierarchies of Semantics and Proof Methods [CC92b], [Cou02];
- Typing & Type Inference [Cou97];
- (Abstract) Model Checking [CC00];
- Program Transformation (including compile-time program optimization, partial evaluation, etc) [CC02];

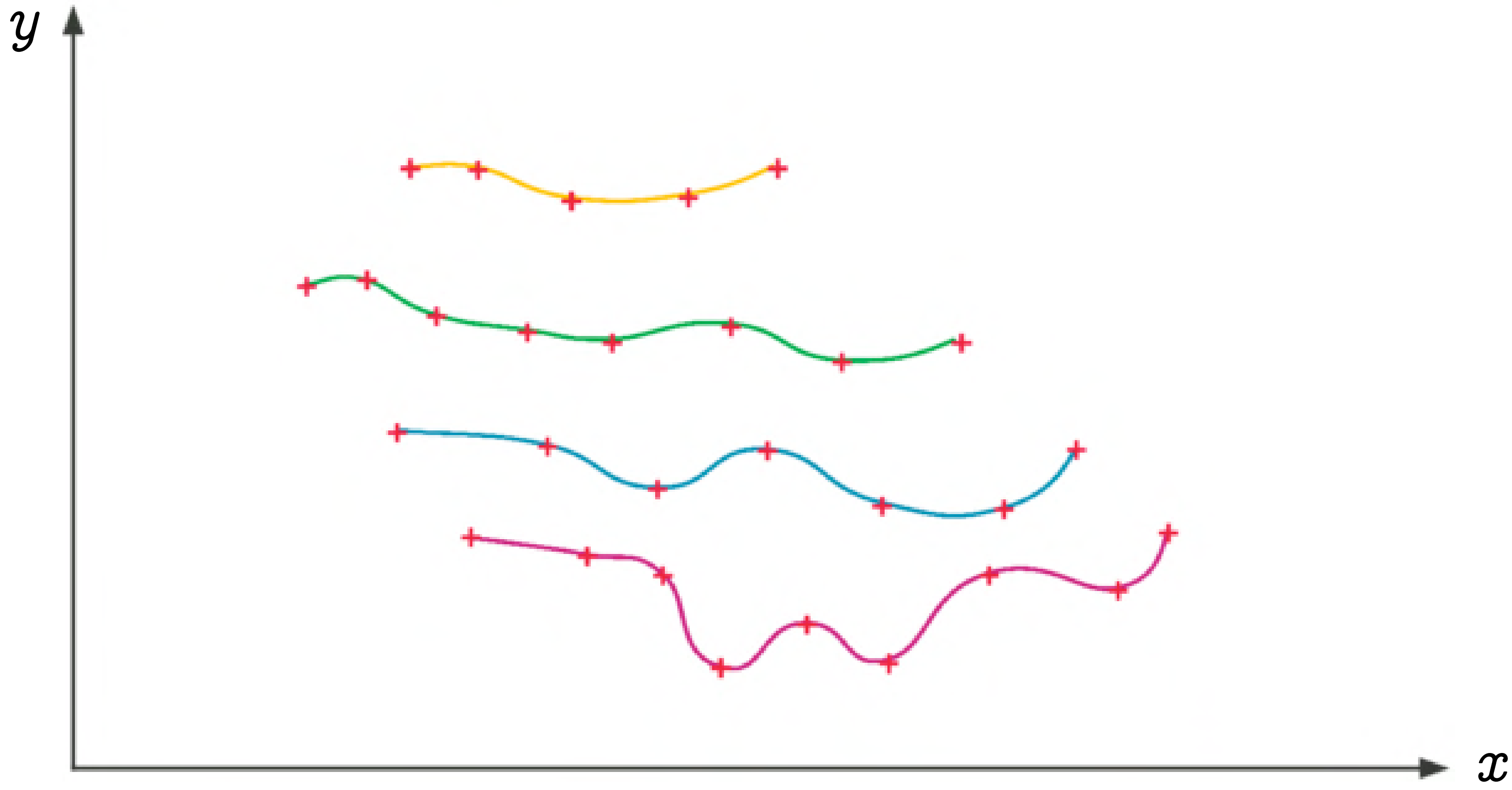
Applications of Abstract Interpretation (Cont'd)

– Software Watermarking [CC04];
– Bisimulations [RT04, RT06];
– Language-based security [GM04];
– Semantics-based obfuscated malware detection [PCJD07].
– Databases [AGM93, BPC01, BS97]
– Computational biology [Dan07]
– Quantum computing [JP06, Per06]

All these techniques involve sound approximations that can be formalized by abstract interpretation

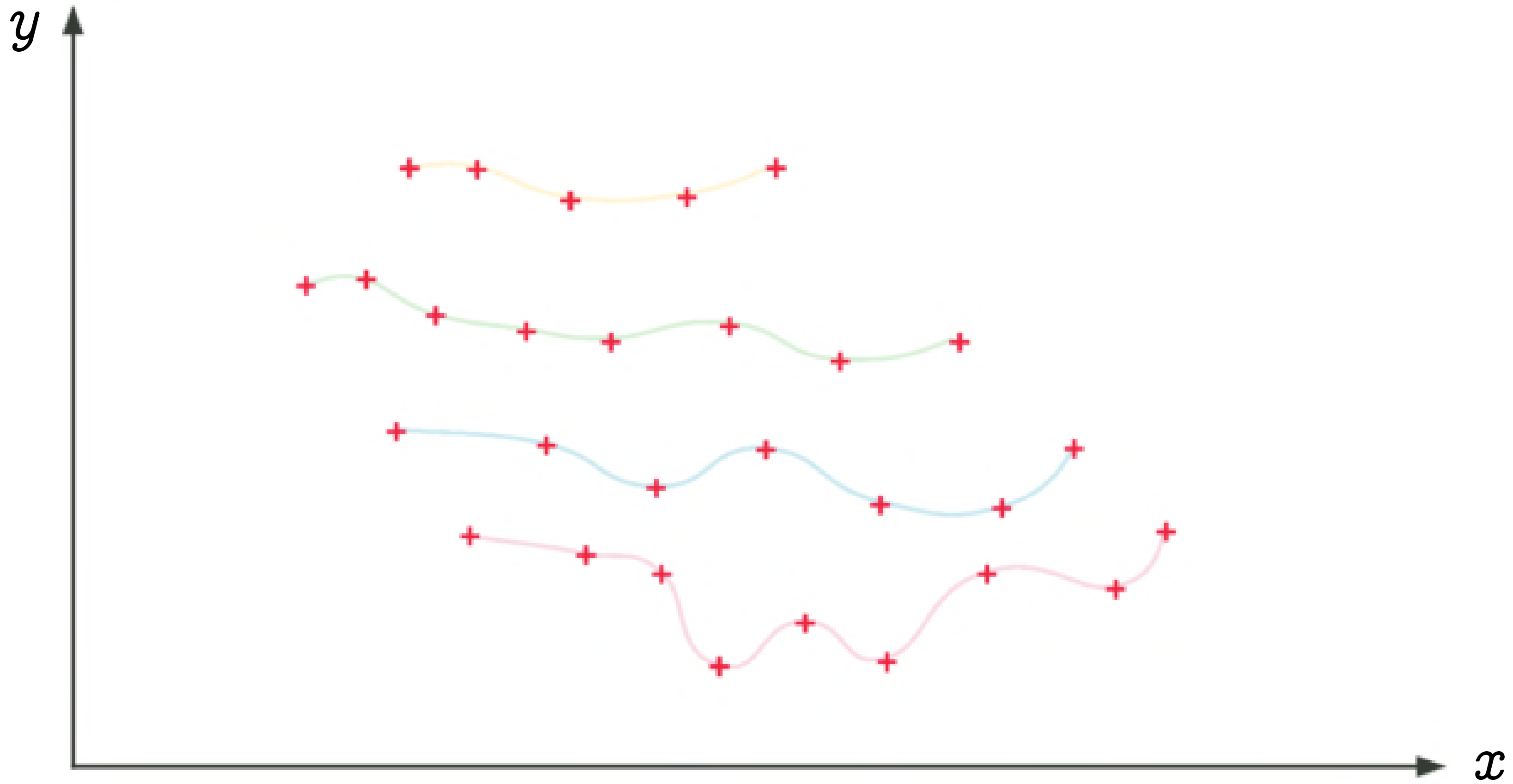
5. Application of Abstract Interpretation to Static Analysis

Semantics



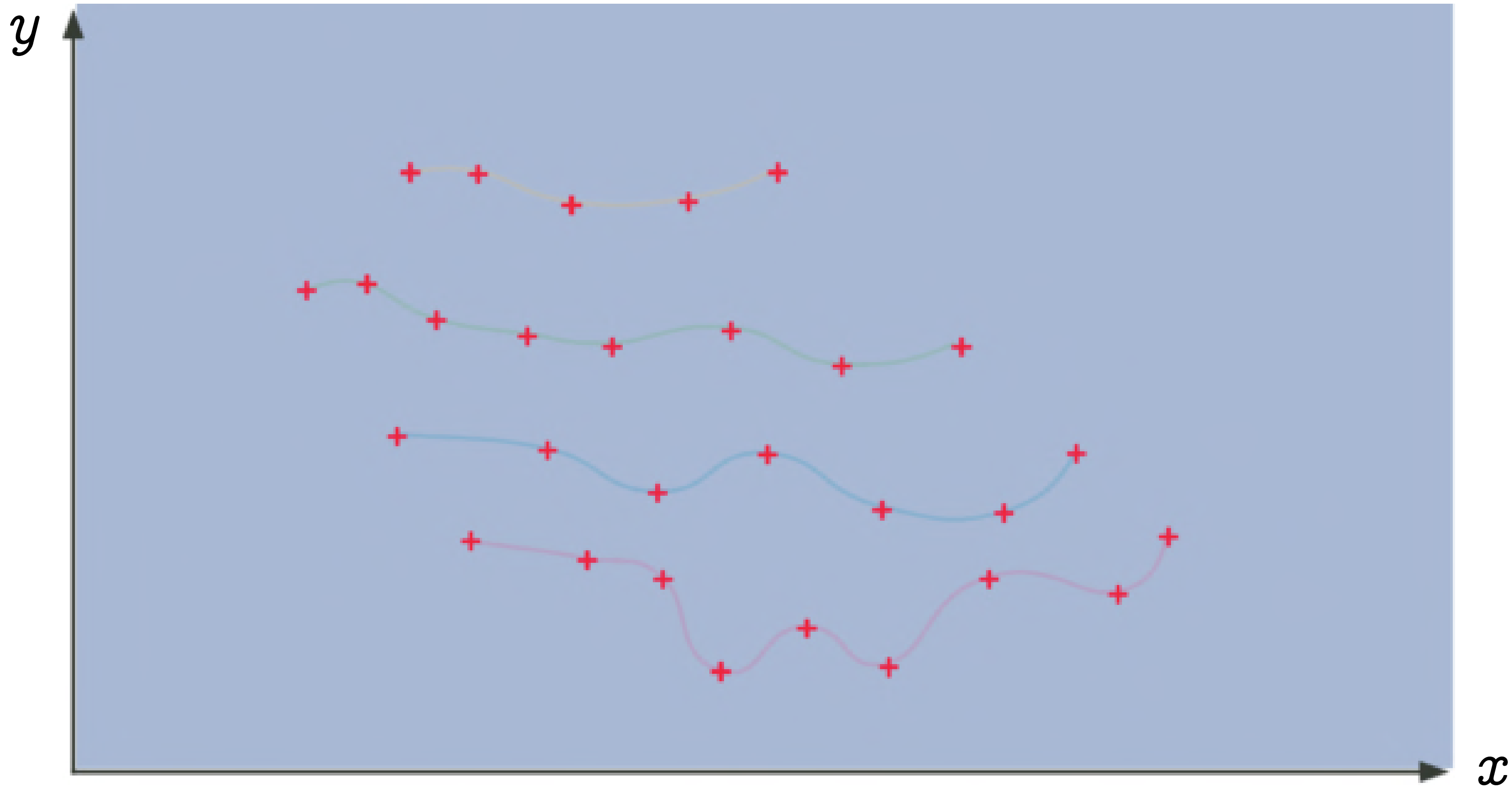
(Infinite) set of traces (finite ou infinite)

Abstraction to a set of states (invariant)



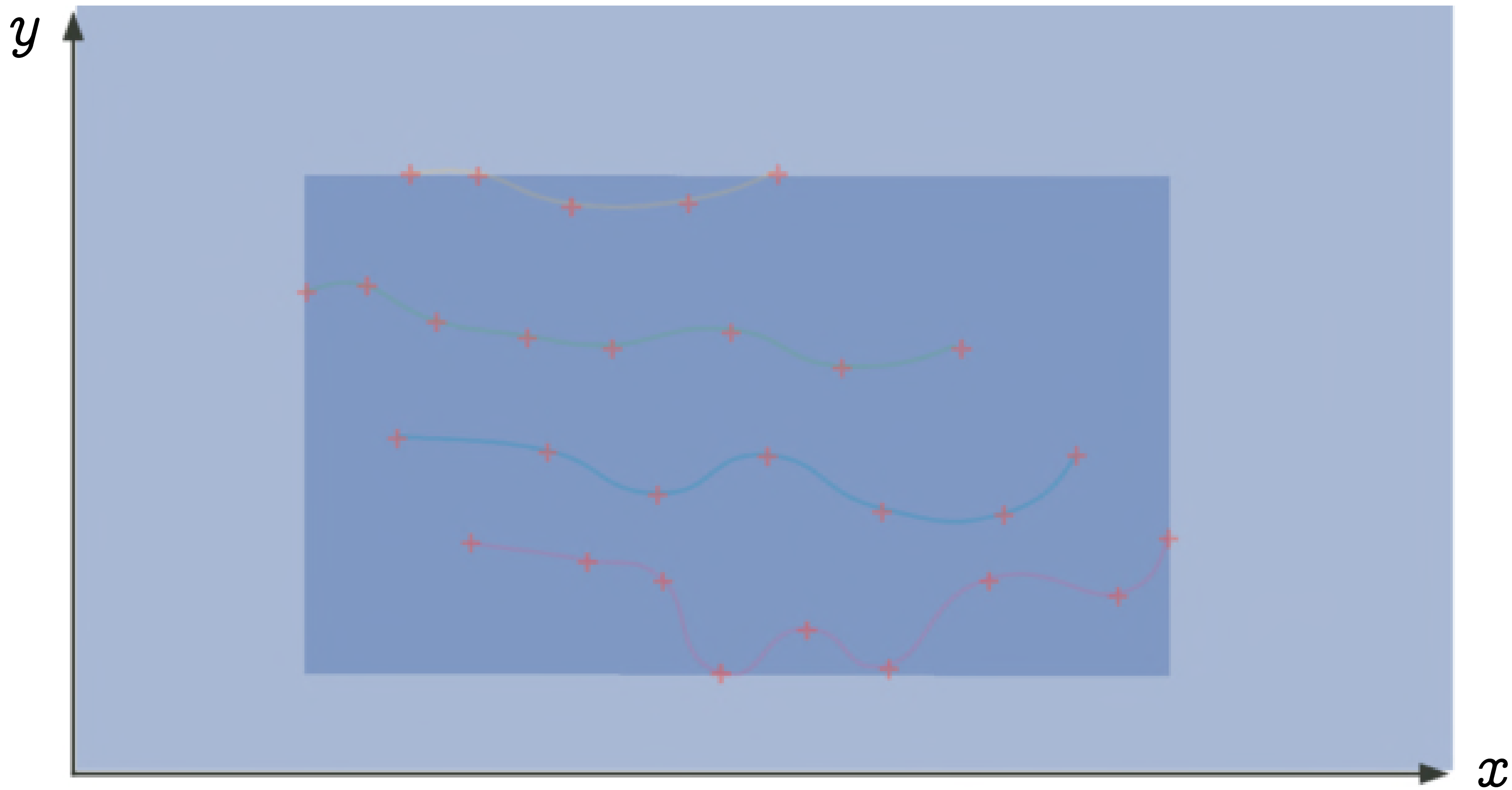
Set of points $\{(x_i, y_i) : i \in \Delta\}$, Floyd/Hoare/Naur invariance proof method [Cou02]

Abstraction by signs



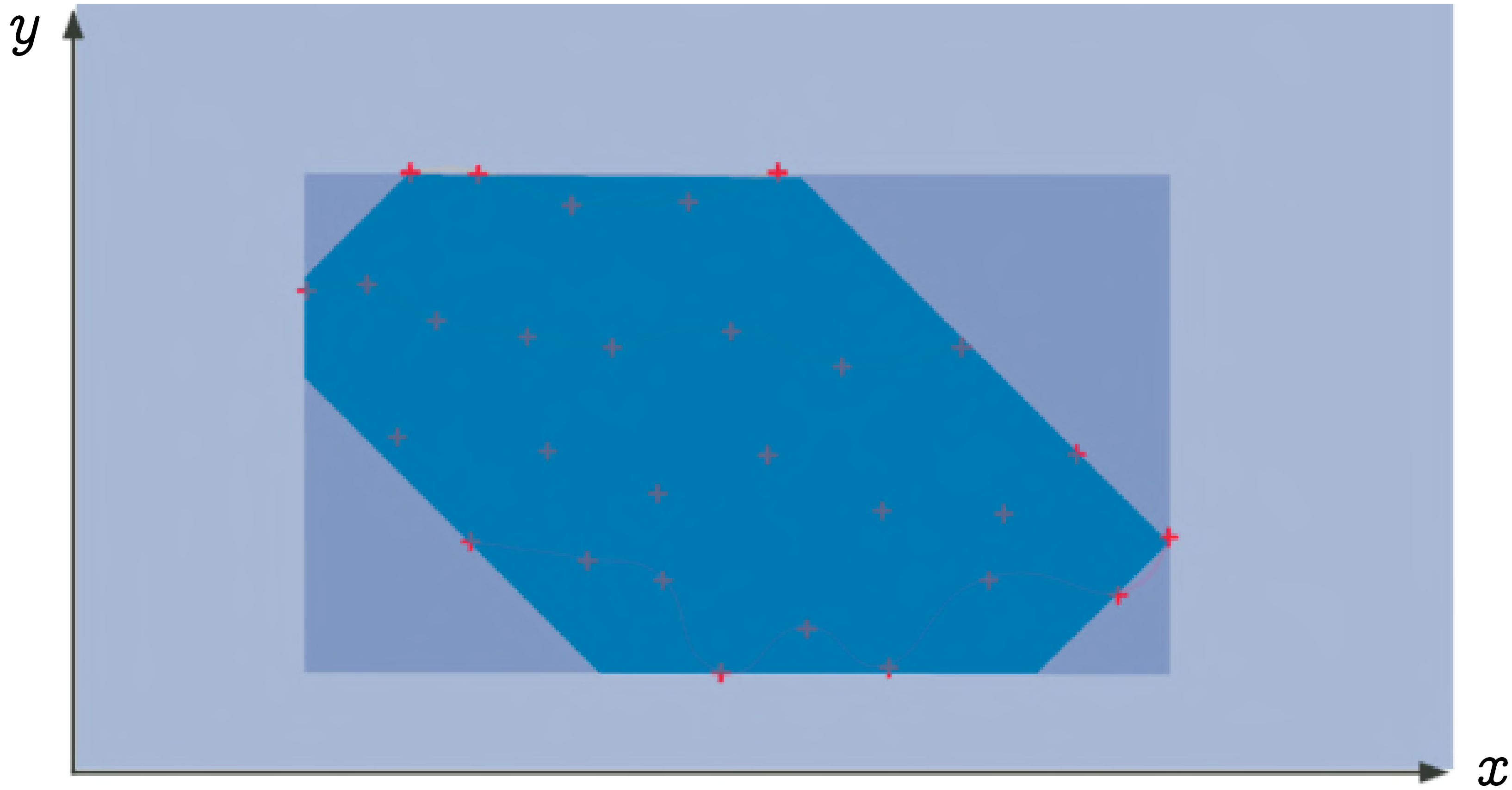
Signs $x \geq 0$, $y \geq 0$ [CC79]

Abstraction by intervals



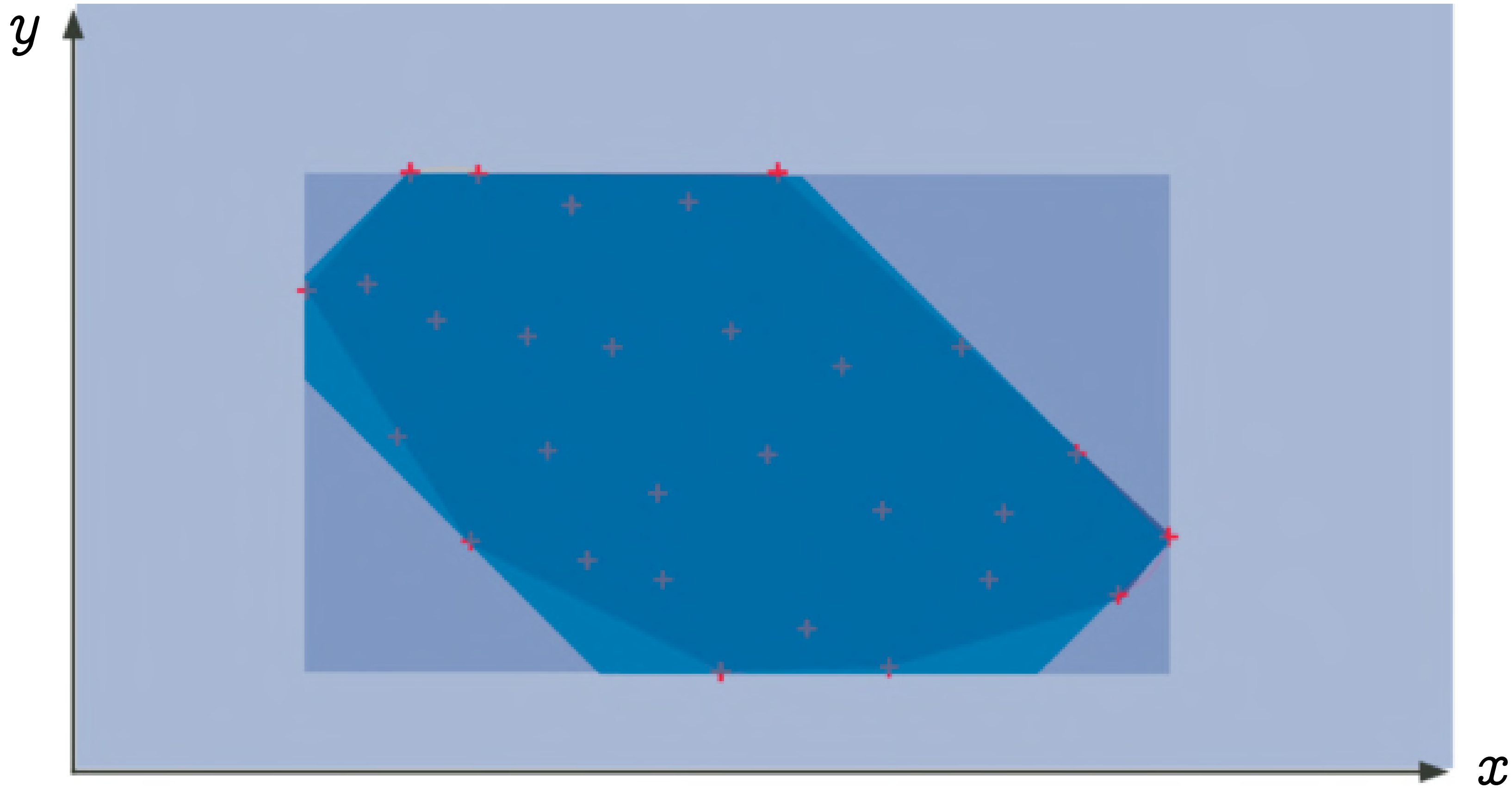
Intervals $a \leq x \leq b$, $c \leq y \leq d$ [CC77]

Abstraction by octagons



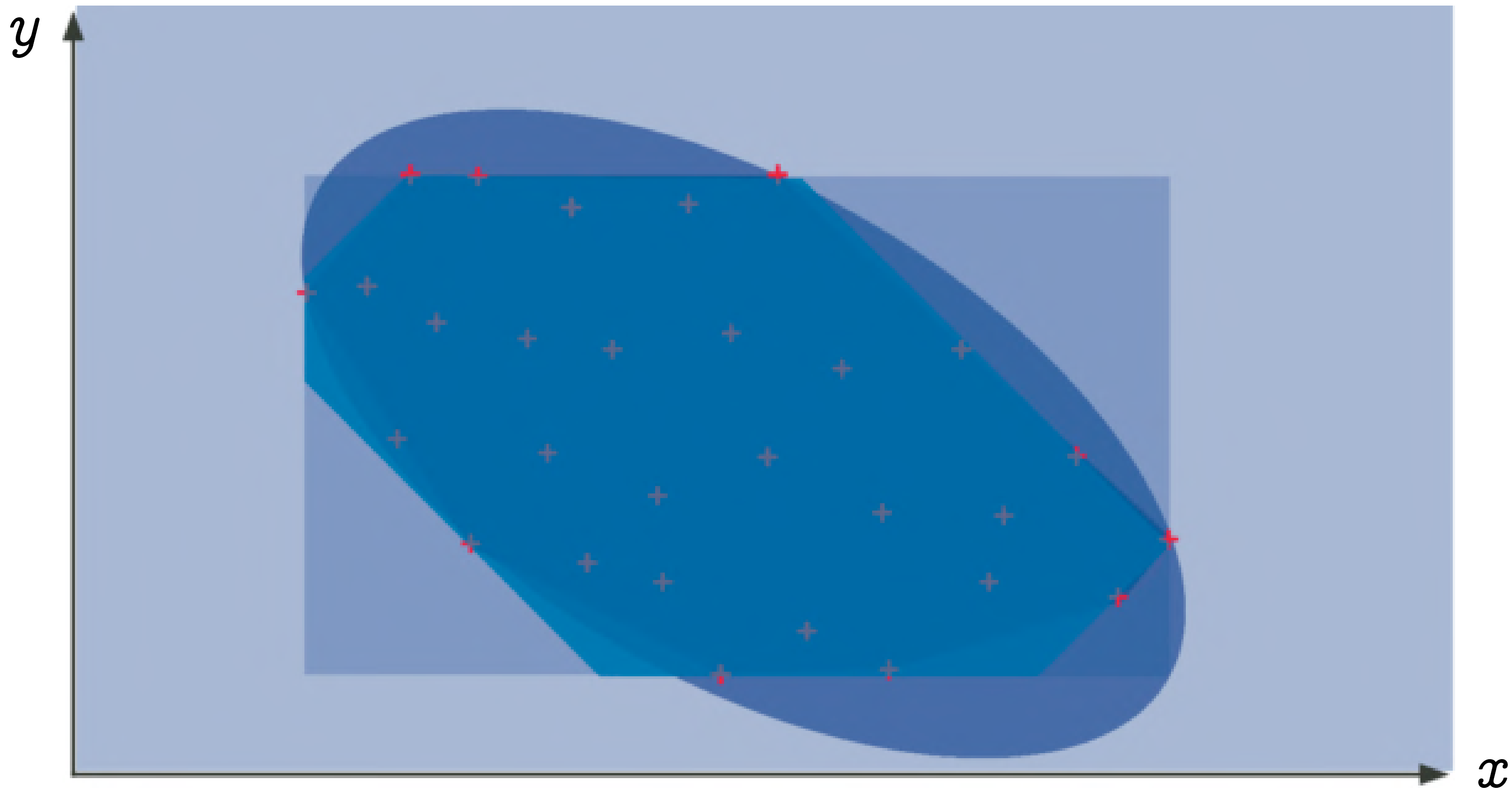
Octagons $x - y \leq a$, $x + y \leq b$ [Min06]

Abstraction by polyedra



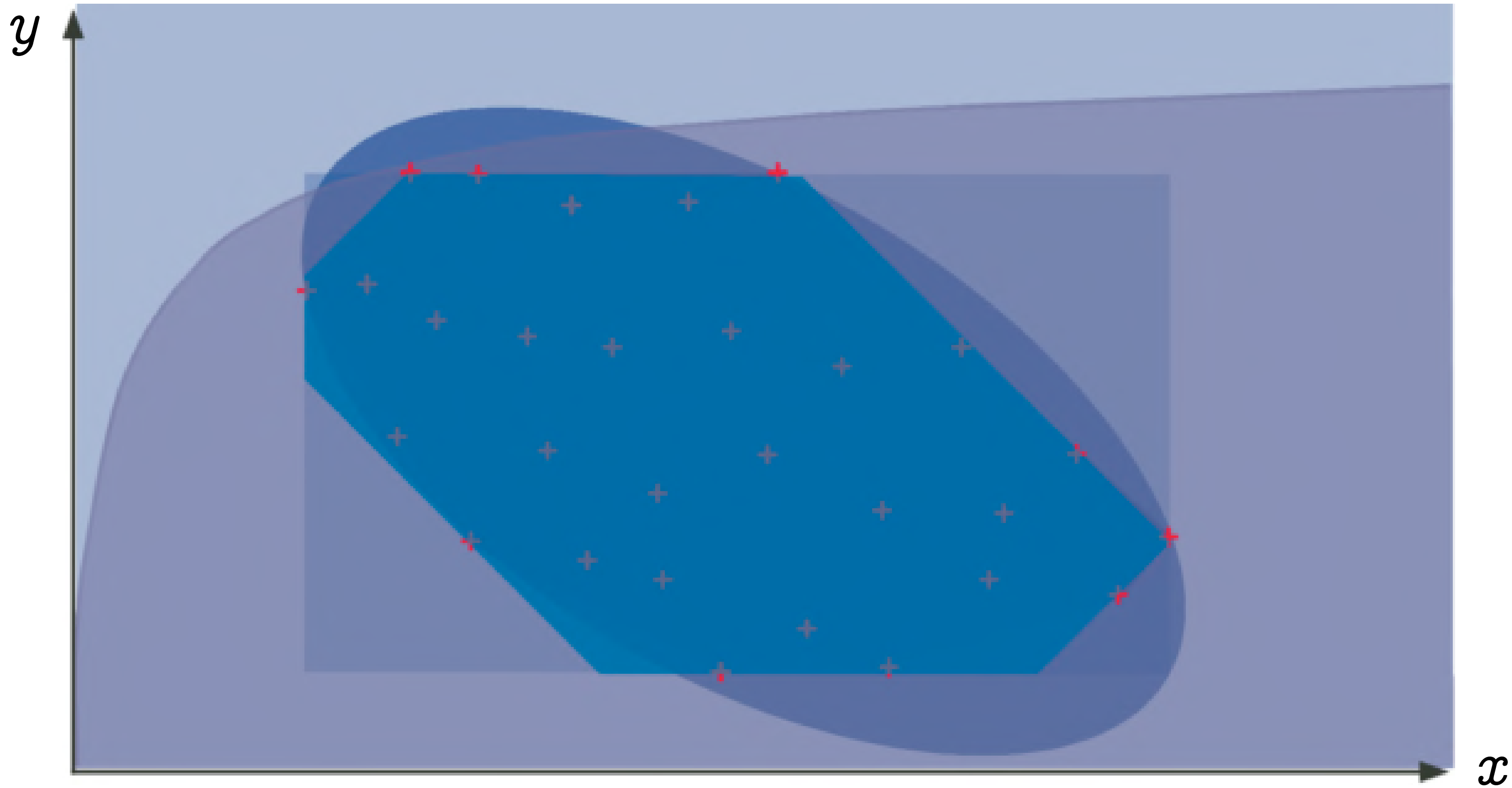
Polyedra $a.x + b.y \leq c$ [CH78]

Abstraction by ellipsoids



Ellipsoids $(x - a)^2 + (y - b)^2 \leq c$ [Fer05b]

Abstraction by exponentials



Exponentials $a^x \leq y$ [Fer05a]

6. Invariant Computation by Fixpoint Approximation [CC77]

Fixpoint equation

$\{y \geqslant 0\}$ ← hypothesis

```
x = y
```

$\{I(x, y)\}$ ← loop invariant

```
while (x > 0) {
  x = x - 1;
}
```

Floyd-Naur-Hoare verification conditions:

$$(y \geqslant 0 \wedge x = y) \Longrightarrow I(x, y) \qquad \textit{initialisation}$$

$$(I(x, y) \wedge x > 0 \wedge x' = x - 1) \Longrightarrow I(x', y) \qquad \textit{iteration}$$

Equivalent fixpoint equation:

$$I(x, y) = x \geqslant 0 \wedge (x = y \vee I(x + 1, y)) \qquad (\textit{i.e. } I = F(I)\,^{(5)})$$

(5) We look for the most precise invariant I, implying all others, that is $\mathsf{lfp}^{\Rightarrow} F$.

Accelerated Iterates $I = \lim_{n\to\infty} F^n(\text{false})$

$$I^0(x,y) = \text{false}$$

$$\begin{aligned} I^1(x,y) &= x \geqslant 0 \wedge (x = y \vee I^0(x+1,y)) \\ &= 0 \leqslant x = y \end{aligned}$$

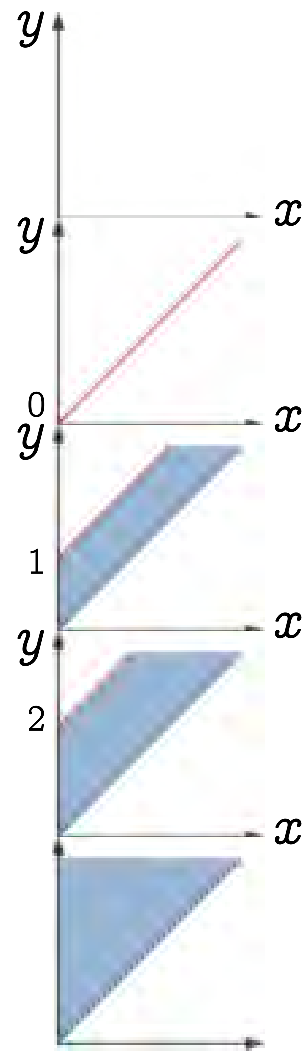
$$\begin{aligned} I^2(x,y) &= x \geqslant 0 \wedge (x = y \vee I^1(x+1,y)) \\ &= 0 \leqslant x \leqslant y \leqslant x+1 \end{aligned}$$

$$\begin{aligned} I^3(x,y) &= x \geqslant 0 \wedge (x = y \vee I^2(x+1,y)) \\ &= 0 \leqslant x \leqslant y \leqslant x+2 \end{aligned}$$

$$\begin{aligned} I^4(x,y) &= I^2(x,y) \,\nabla\, I^3(x,y) \leftarrow \text{widening} \\ &= 0 \leqslant x \leqslant y \end{aligned}$$

$$\begin{aligned} I^5(x,y) &= x \geqslant 0 \wedge (x = y \vee I^4(x+1,y)) \\ &= I^4(x,y) \quad \text{fixed point!} \end{aligned}$$

The invariants are computer representable with octagons!



7. Scaling up

The difficulty of scaling up

– The abstraction must be coarse enough to be effectively computable with reasonable resources

– The abstraction must be precise enough to avoid false alarms

– Abstractions to *infinite domains with widenings* are more expressive than abstractions to *finite domains* (when considering the analysis of a programming language) [CC92a]

– Abstractions are ultimately incomplete (even intrinsically for some semantics and specifications [CC00])

Abstraction/refinement by tuning the cost/precision ratio in ASTRÉE

– Approximate reduced product of a choice of coarsenable/refinable abstractions

– Tune their precision/cost ratio by

- Globally by parametrization
- Locally by (automatic) analysis directives

so that the overall abstraction is <u>not</u> uniform.

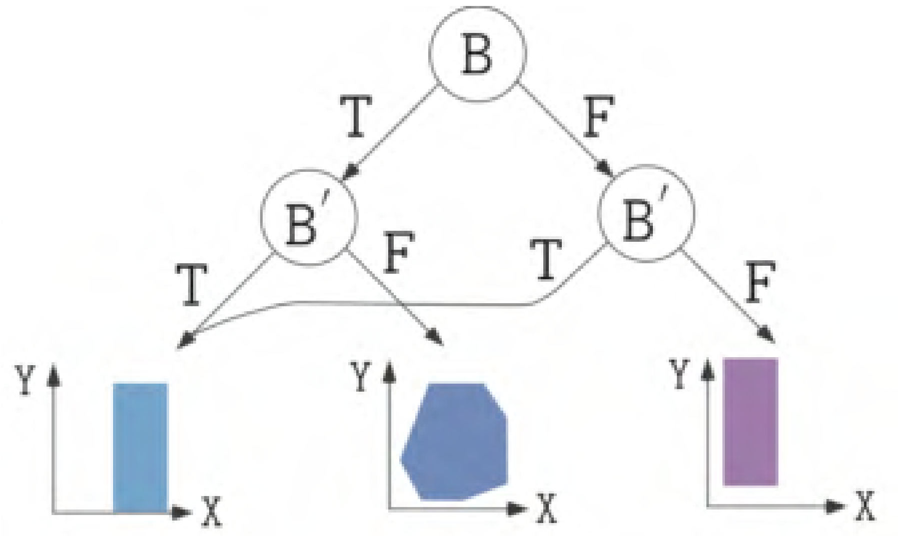
Example of abstract domain choice in ASTRÉE

```
/* Launching the forward abstract interpreter */
/* Domains:  Guard domain, and Boolean packs (based on Absolute
value equality relations, and Symbolic constant propagation
(max_depth=20), and Linearization, and Integer intervals, and
congruences, and bitfields, and finite integer sets, and Float
intervals), and Octagons, and High_passband_domain(10), and
Second_order_filter_domain (with real roots)(10), and
Second_order_filter_domain (with complex roots)(10), and
Arithmetico-geometric series, and new clock, and Dependencies
(static), and Equality relations, and Modulo relations, and
Symbolic constant propagation (max_depth=20), and Linearization,
and Integer intervals, and congruences, and bitfields, and
finite integer sets, and Float intervals.  */
```

Example of abstract domain functor in ASTRÉE: decision trees

– Code Sample:

```
/* boolean.c */
typedef enum {F=0,T=1} BOOL;
BOOL B;
void main () {
  unsigned int X, Y;
  while (1) {
    ...
    B = (X == 0);
    ...
    if (!B) {
      Y = 1 / X;
    }
    ...
  }
}
```



The boolean relation abstract domain is parameterized by the height of the decision tree (an analyzer option) and the abstract domain at the leafs

Reduction [CC79, CCF^{+}08]

Example: reduction of intervals [CC76] by simple congruences [Gra89]

```
% 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 }
% astree congruence.c -no-relational -exec-fn main |& egrep "(WARN)|(X in)"
direct = <integers (intv+cong+bitfield+set): X in {132} >
```

Intervals : $X \in [129, 132]$ + congruences : $X = 0 \mod 4 \Longrightarrow$ $X \in \{132\}$.

Parameterized abstractions

– Parameterize the cost / precision ratio of abstractions in the static analyzer

– Examples:

- array smashing: `--smash-threshold` n (400 by default)
  $\rightarrow$ smash elements of arrays of size $> n$, otherwise individualize array elements (each handled as a simple variable).

- packing in octogons: (to determine which groups of variables are related by octagons and where)
  · `--fewer-oct`: no packs at the function level,
  · `--max-array-size-in-octagons` n: unsmashed array elements of size $> n$ don't go to octagons packs

Parameterized widenings

– Parameterize the rate and level of precision of widenings in the static analyzer

– Examples:

  - delayed widenings: `--forced-union-iterations-at-beginning` n (2 by default)

  - thresholds for widening (e.g. for integers):

0; 1; 2; 3; 4; 5; 32767; 32768; 65535; 65536; 2147483647; 2147483648; 4294967295.

Analysis directives

– Enable a local refinement of an abstract domain

– Example:

```
% cat repeat1.c
typedef enum {FALSE=0,TRUE=1} BOOL;
int main () {
  int x = 100; BOOL b = TRUE;

  while (b) {
    x = x - 1;
    b = (x > 0);
  }
}
% astree -exec-fn main repeat1.c |& egrep "WARN"
repeat1.c:5.8-13::[call#main@2:loop@4>=4:]: WARN: signed int arithmetic
range [-2147483649, 2147483646] not included in [-2147483648, 2147483647]
%
```

Example of directive (Cont'd)

```
% cat repeat2.c
typedef enum {FALSE=0,TRUE=1} BOOL;
int main () {
  int x = 100; BOOL b = TRUE;
 __ASTREE_boolean_pack((b,x));
  while (b) {
    x = x - 1;
    b = (x > 0);
  }
}
```

```
% astree -exec-fn main repeat2.c |& egrep "WARN"
%
```

The insertion of this directive could be automated in ASTRÉE (if the considered family of programs has "repeat" loops).

Automatic analysis directives

– The directives can be inserted automatically by static analysis

– Example:

```
% cat p.c
int clip(int x, int max, int min) {
 if (max >= min) {
  if (x <= max) {
   max = x;
  }
  if (x < min) {
   max = min;
  }
 }
 return max;
}
void main() {
 int m = 0; int M = 512; int x, y;
 y = clip(x, M, m);
  __ASTREE_assert(((m<=y) && (y<=M)));
}
% astree -exec-fn main p.c |& grep WARN
%
```

```
% astree -exec-fn main p.c -dump-partition
...
int (clip)(int x, int max, int min)
{
  if ((max >= min))
  {  __ASTREE_partition_control((0))
    if ((x <= max))
    {
      max = x;
    }
    if ((x < min))
    {
      max = min;
    }
    __ASTREE_partition_merge_last(());
  }
  return max;
}
...
%
```

Adding new abstract domains

- The weakest invariant to prove the specification may not be expressible with the current refined abstractions $\Rightarrow$ false alarms cannot be solved

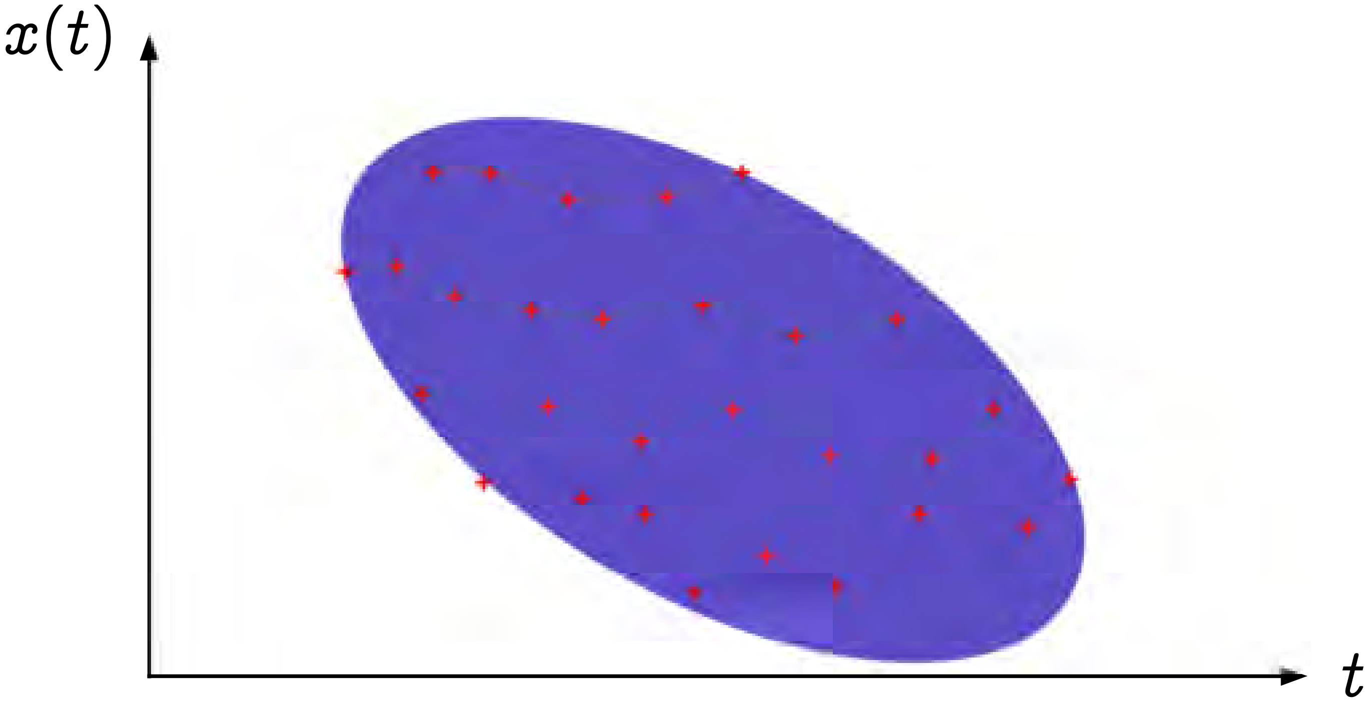
- No solution, but adding a new abstract domain:

  - representation of the abstract properties

  - abstract property transformers for language primitives
  - widening
  - reduction with other abstractions

- Examples : ellipsoids for filters [Fer05b], exponentials for accumulation of small rounding errors [Fer05a], quaternions, ...

Abstraction by ellipsoid for filters

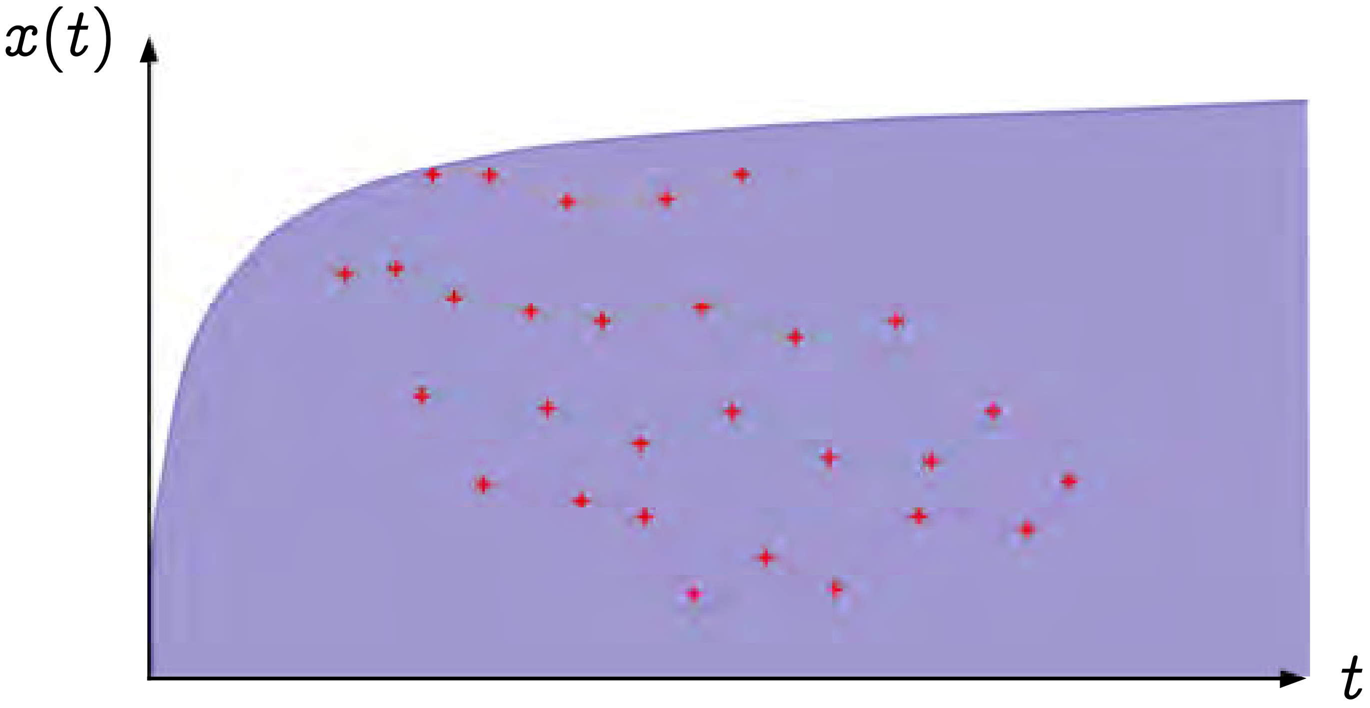


Ellipsoids $(x-a)^2 + (y-b)^2 \leq c$ [Fer05b]

Example of analysis by ASTRÉE

```
typedef enum {FALSE = 0, TRUE = 1} BOOLEAN;
BOOLEAN INIT; float P, X;
void filter () {
  static float E[2], S[2];
  if (INIT) { S[0] = X; P = X; E[0] = X; }
  else { P = (((((0.5 * X) - (E[0] * 0.7)) + (E[1] * 0.4))
             + (S[0] * 1.5)) - (S[1] * 0.7)); }
  E[1] = E[0]; E[0] = X; S[1] = S[0]; S[0] = P;
  /* S[0], S[1] in [-1327.02698354, 1327.02698354] */
}
void main () { X = 0.2 * X + 5; INIT = TRUE;
  while (1) {
    X = 0.9 * X + 35; /* simulated filter input */
    filter (); INIT = FALSE; }
}
```

Abstraction by exponentials for accumulation of small rounding errors



Exponentials $a^x \leq y$

Example of analysis by ASTRÉE

```
% cat retro.c
typedef enum {FALSE=0, TRUE=1} BOOL;
BOOL FIRST;
volatile BOOL SWITCH;
volatile float E;
float P, X, A, B;

void dev( )
{ X=E;
  if (FIRST) { P = X; }
  else
    { P =  (P - ((((2.0 * P) - A) - B)
               * 4.491048e-03)); };
  B = A;
  if (SWITCH) {A = P;}
  else {A = X;}
}
```

```
void main()
{ FIRST = TRUE;
  while (TRUE) {
    dev( );
    FIRST = FALSE;
    __ASTREE_wait_for_clock(());
  }}
% cat retro.config
__ASTREE_volatile_input((E [-15.0, 15.0]));
__ASTREE_volatile_input((SWITCH [0,1]));
__ASTREE_max_clock((3600000));
```

```
|P| <= (15.  + 5.87747175411e-39
/ 1.19209290217e-07) * (1 +
1.19209290217e-07)^clock - 5.87747175411e-39
/ 1.19209290217e-07 <= 23.0393526881
```

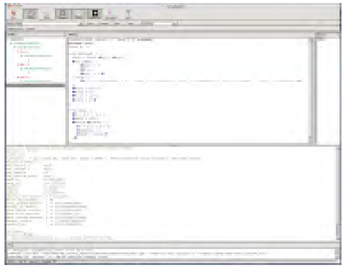
8. Industrial Application of Abstract Interpretation

Examples of static analyzers in industrial use

– For C critical synchronous embedded control/command programs (for example for Electric Flight Control Software)

– aiT [FHL+01] is a static analyzer to determine the Worst Case Execution Time (to guarantee synchronization in due time)

– Astrée [BCC+03] is a static analyzer to verify the absence of runtime errors



Industrial results obtained with ASTRÉE

Automatic proofs of absence of runtime errors in Electric Flight Control Software:

– Software 1 : 132.000 lines of C, 40mn on a PC 2.8 GHz, 300 megabytes (nov. 2003)

– Software 2 : 1.000.000 lines of C, 34h, 8 gigabytes (nov. 2005)

no false alarm

World premières !

9. Conclusion on Future Propects of Abstract Interpretation

Evolution of Software Engineering

- State of the Art in Software Engineering: Manual validation by control of the software design process
- Desirable Evolution of Software Engineering: Automatic verification of the final product

Challenges in Abstract Interpretation

Short term : automatic help on the diagnosis of the origin of alarms

Midterm : Parallelism

Long term : Liveness for infinite state systems

THE END

Thank you for your attention

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