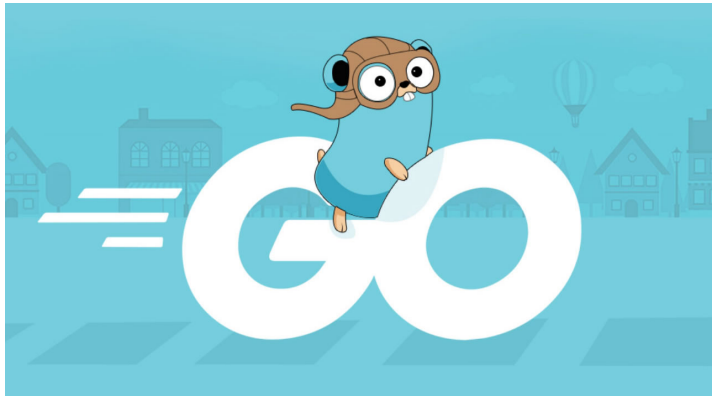
Go2Pins: a framework for the LTL verification of Go programs

A. Kirszenberg, A. Martin, H. Moreau, and E. Renault

July 12, 2021

The Go programming language



- Designed at Google in 2009
  - Used by Docker, Google, Facebook, Soundcloud, ...
  - 308,480 repositories on GitHub (as of June, 25th)
- Inspired by Hoare [1985] Communicating Sequential Processes (CSP)
- Communication using channels

A simple example

```
1  func fibo(n int) int {
2    n0 := 0
3    n1 := 1
4    for i := 0; i < n; i++ {
5      n2 := n0 + n1
6      n0 = n1
7      n1 = n2
8    }
9    return n1
10 }
11
12 func main() {
13     a := 1
14     for ; a < 10; {
15           a = fibo(5)
16     }
17 }
```

Fibonacci computation in Go

A simple example

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Fibonacci computation in Go

How to ensure that this program loops infinitely?

A simple example

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```

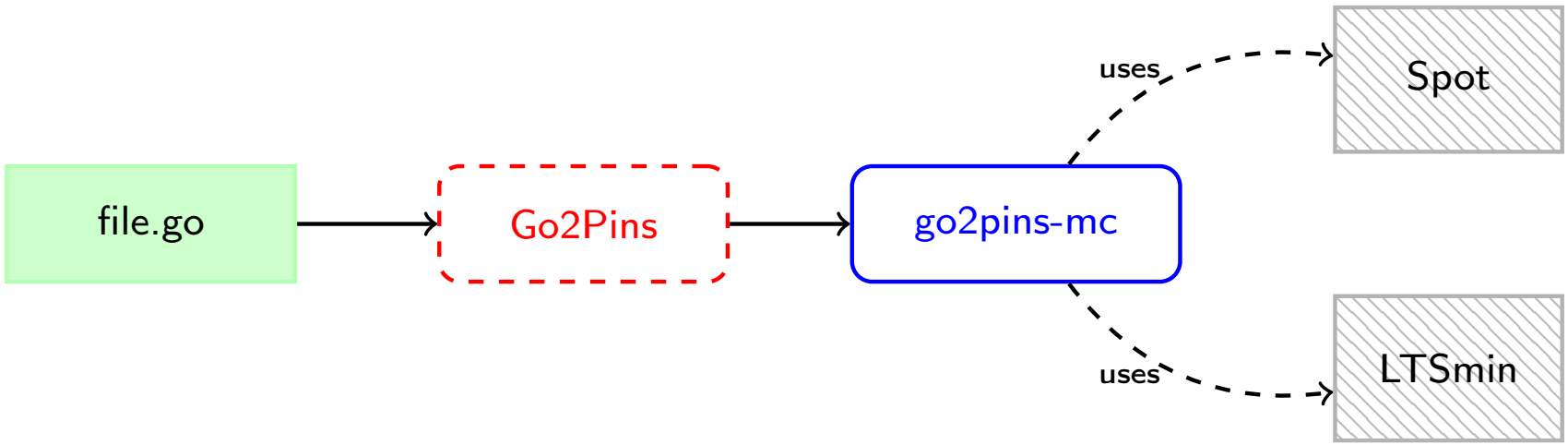
Fibonacci computation in Go

How to ensure that this program loops infinitely?

Check the LTL property
G "a < 10"

Introducing Go2Pins

A framework for the LTL verification of Go programs

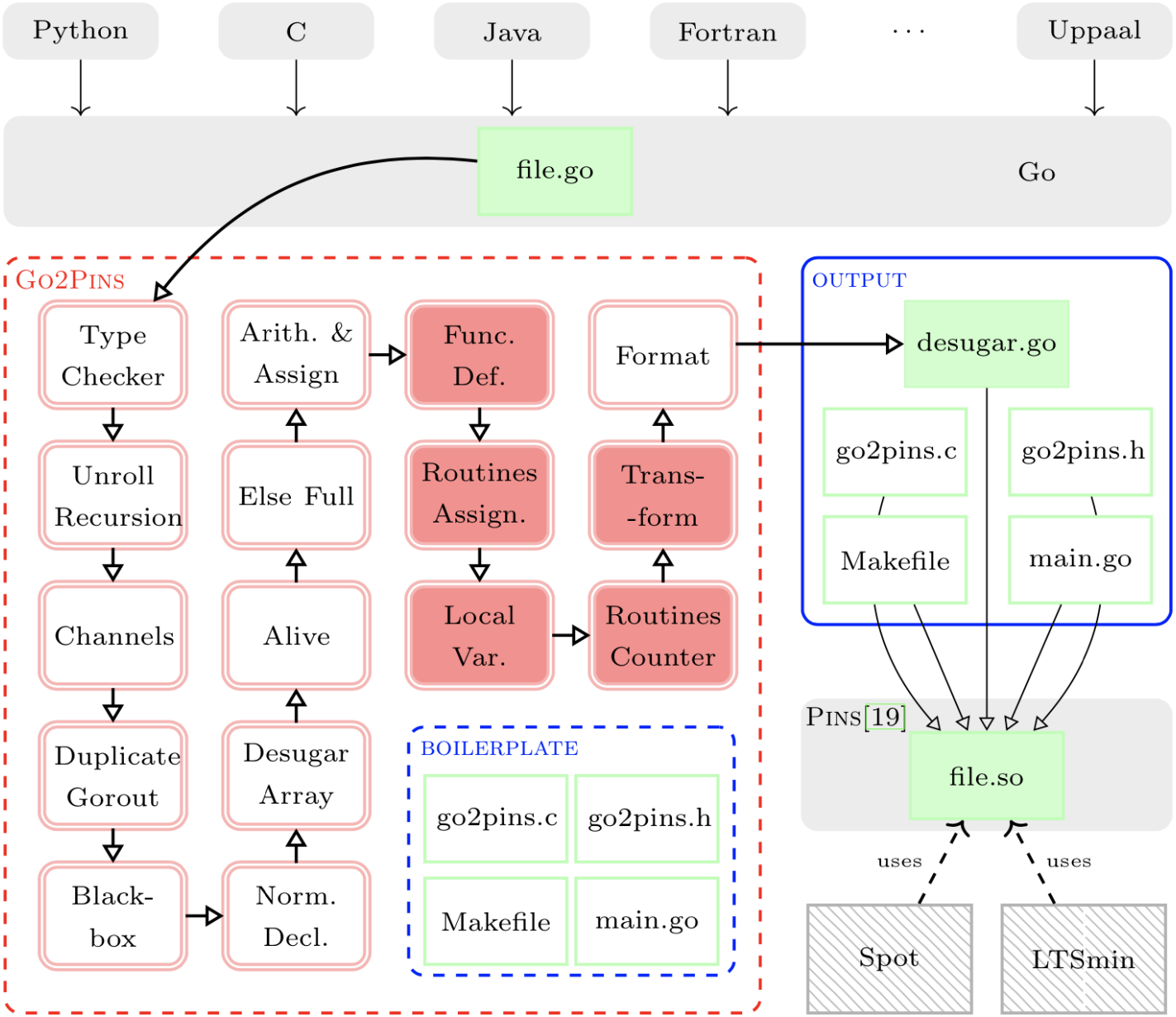


Go2Pins: overview

- A transpiler that translates the input Go program into an output Go program
  - Benefits from both the reflexivity and the standard library
  - Work in steps, each step desugaring a specific feature from the AST

- The output respects the PINS interface [Kant et al., 2015].
  - One function for retrieving the initial state of the system,
  - One for computing the successors of a state,
  - A state is represented as a vector of integer
  - *Any program that exposes this interface is compatible with any (explicit or symbolic) model checking solution that supports it*

Go2Pins: architecture



Core translation: step 1

Build a (finite) state vector for the program

```
1  func fibo(n int) int {
2    n0 := 0
3    n1 := 1
4    for i := 0; i < n; i++ {
5      n2 := n0 + n1
6      n0 = n1
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8    }
9    return n1
10 }
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12 func main() {
13     a := 1
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16     }
17 }
```

a
n
n0
n1
n2
i
is_alive_a
is_alive_n1
is_alive_n0
is_alive_n2
res0
PC_1
PC_2
fibo caller
fibo callerLabel
main caller
main callerLabel

Core translation: step 2

Extract *atomic* operations

```
1  func fibo(n int) int {
2    n0 := 0
3    n1 := 1
4    for i := 0; i < n; i++ {
5      n2 := n0 + n1
6      n0 = n1
7      n1 = n2
8    }
9    return n1
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12 func main() {
13     a := 1
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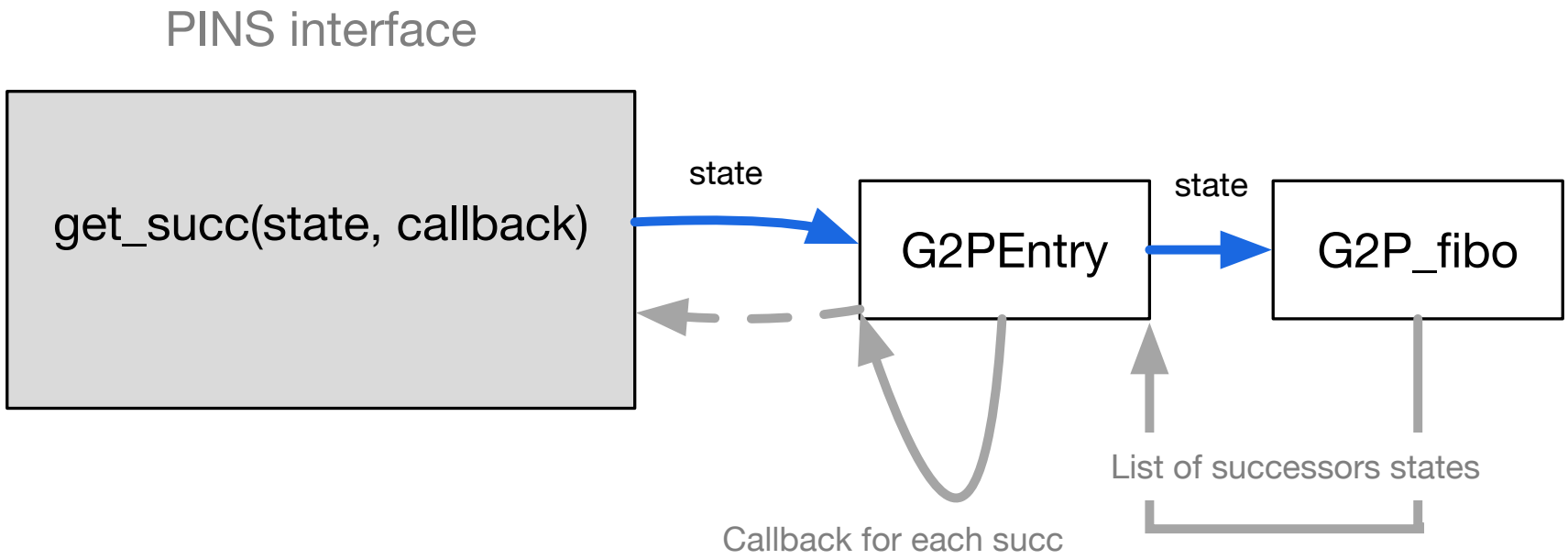
```

```
1  type state [17]int
2  func G2PF_fibo(s state) state{
3    switch s.LabelCounter {
4      case 0: goto label0
5      //...
6      case 12: goto label12
7    }
8    label0: // n0 := 0
9      s.fibo.n0 = 0
10     s.LabelCounter = 1
11     s.fibo.isalive = 1
12     return s
13   //...
14   label12: // return n1
15   s.fibo.res0 = s.fibo.n1
16   s.fibo.FunctionCounter =
17       s.fibo.caller
18   s.fibo.LabelCounter =
19       s.fibo.callerLabel
20   return s
21 }
```

Core translation: step 3

Dispatch to the correct function and fit the PINS interface



Core translation: step 4

Build a package (library) that contains all previous transformations

Link it with the go2pins-mc binary that also provides facilities:

- to list all variables of the transformed program
- to display the state space
- to chose the backend (LTSmin or Spot) to use
- to specify the number of threads to use with this backend
- to check LTL properties
- ...

Handling Concurrency

```
1  var com chan int = make(chan int)
2
3  func producer() {
4          com <- 51
5  }
6
7  func cons() {
8          a := 42
9          a = <-com
10         a = a + 1
11 }
12
13 func main() {
14         go producer()
15         cons()
16 }
```

Producer/consumer in Go

Handling Concurrency

```
1  var com chan int = make(chan int)
2
3  func producer() {
4          com <- 51
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Producer/consumer in Go

How to handle concurrency?

Handling Concurrency

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13 func main() {
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```

Producer/consumer in Go

How to handle concurrency?

G2P_entry contains a scheduler that computes all possibles synchronizations from potential successors

State vector is augmented with slots that are in charge of tracking potential synchronization

Abstraction with Black-Box Transitions (1/2)

How to reduce state space size?

```
1  func fibo(n int) int {
2    n0 := 0
3    n1 := 1
4    for i := 0; i < n; i++ {
5      n2 := n0 + n1
6      n0 = n1
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12 func main() {
13     a := 1
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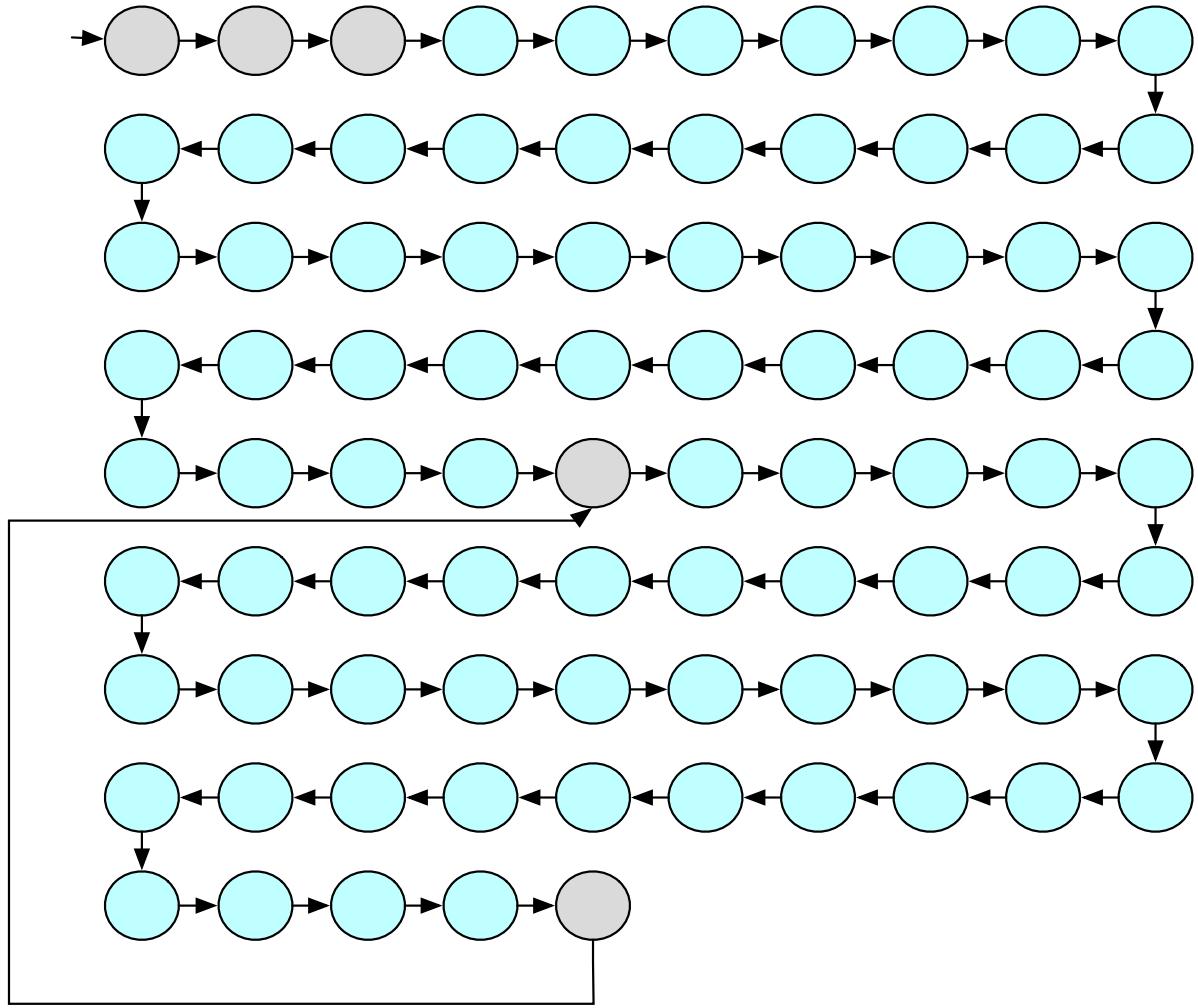
```

85 states
85 transitions



Abstraction with Black-Box Transitions (2/2)

- **Automatically** detect relevant functions based on observed atomic propositions
- Extended to handle global variables (details in the paper)

```
1  func fibo(n int) int {
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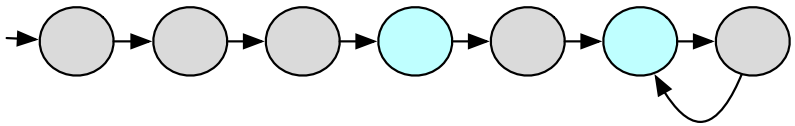


7 states
7 transitions

Some notes on Go2Pins

- **Currently restricted to only integer variables ...**
- ... BUT blackbox transitions can help to support complex types
- ... For instance, we can call any function from the go runtime

- **Can handle recursion ...**
- ... BUT only up to a (user specifiable) fixed depth

- **For now only a fixed number of go-routines are supported**

Related work

- Static analysis of operations on channels
  - [Liu et al., 2016] developed a tool that statically detects patterns of bugs and fix them according to some strategies
  - Other approaches focus on extracting channels operations [Liu et al., 2016; Lange et al., 2018, 2017; Ng and Yoshida, 2016; Dilley and Lange, 2020]
- [Dekker et al., 2014; Giunti, 2020] convert formal program into Go
- JPF [Visser et al., 2018] requires providing the source code of the standard library and relies on a Virtual Machine.
- SPIN atomics, d steps and c code instructions
- Approaches based on LLVM [Zaks and Joshi, 2008,?]

Benchmark: setup

Models:

- 41 files (in C) coming from the RERS challenges
- tranlated using c4go in Go
- resulting in 1 909 345 LOC

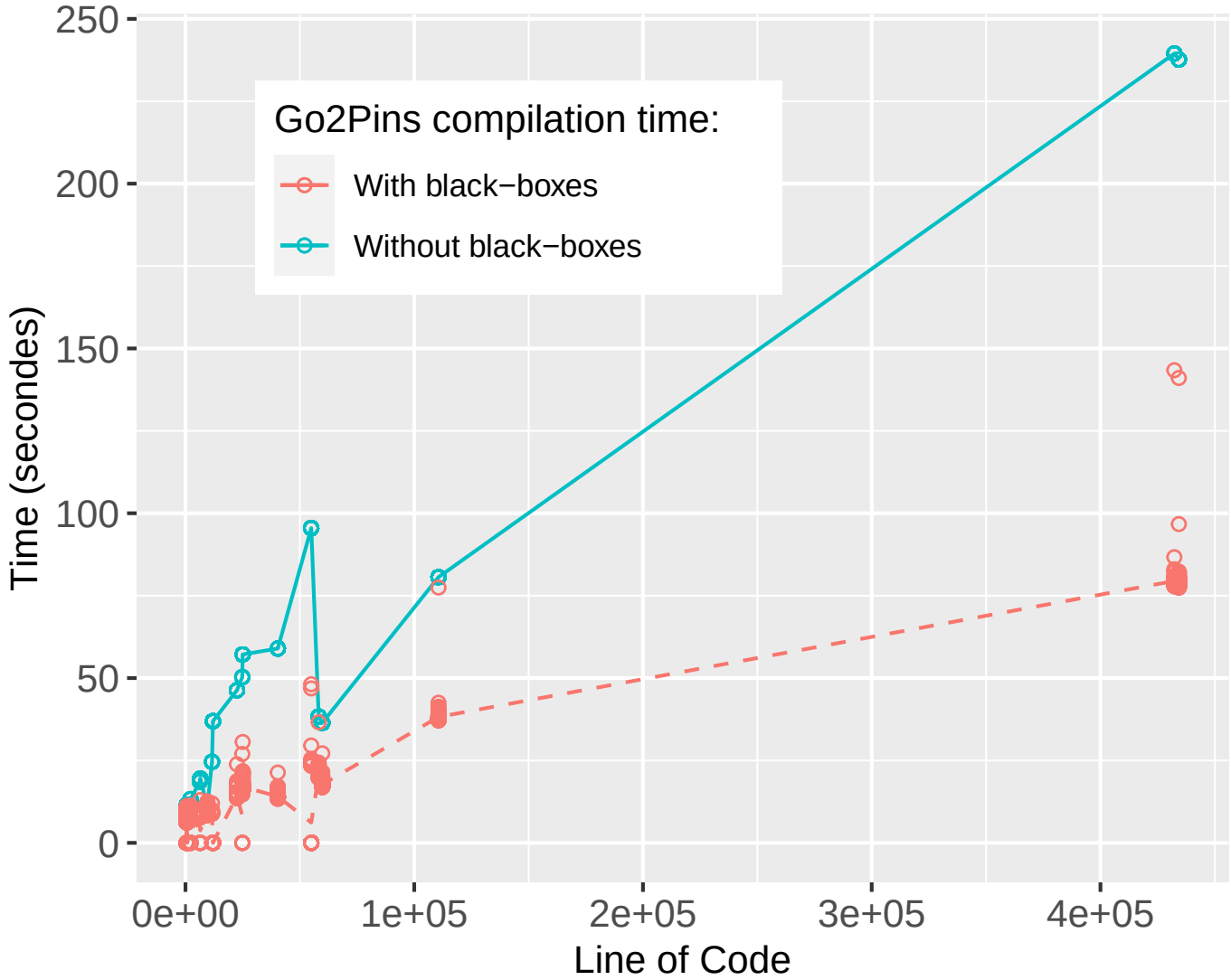
Formulae:

- 5 064 LTL formulae
- 35% are verified and 65% are violated
- 25% pure guarantee, 44% pure safety, 2% pure obligation, 12% pure persistence, 12% pure recurrence, and 5% pure reactivity

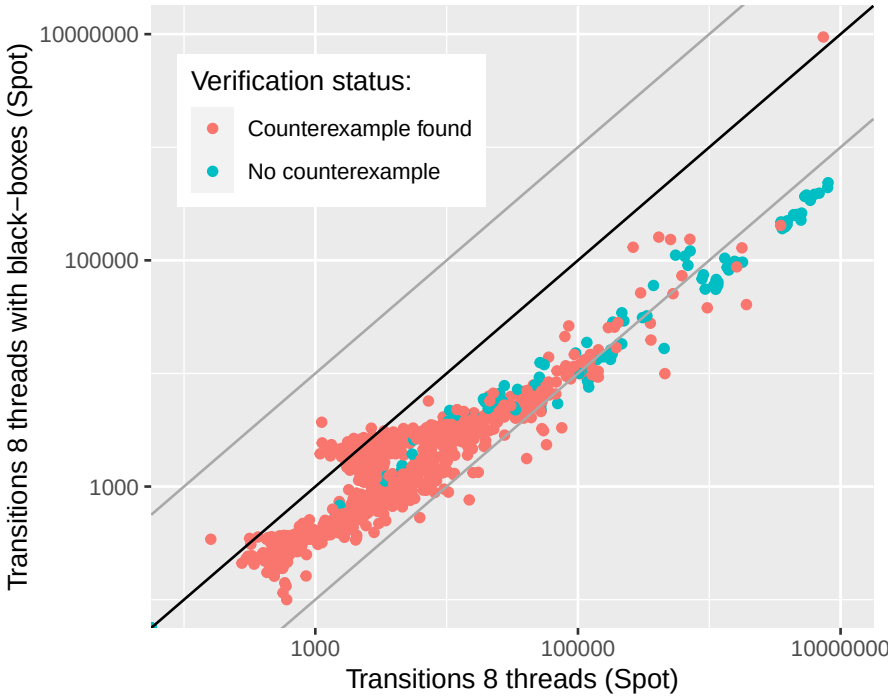
Backend: Spot and LTSmin

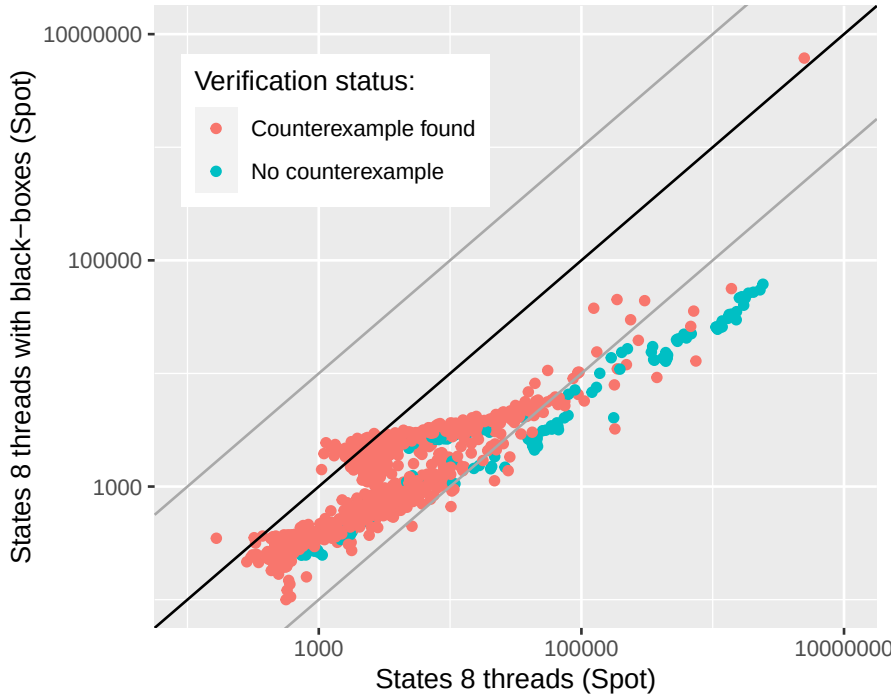
200 Go, 8 threads, 4 minutes timeout on a 24 cores Intel Xeon @2.66GHz

Benchmark: compilation time

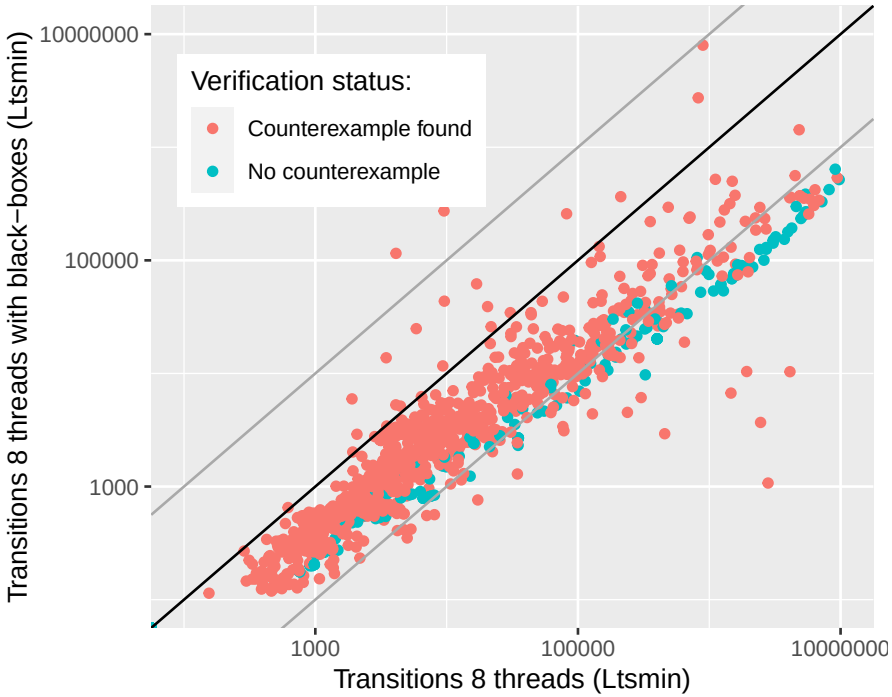


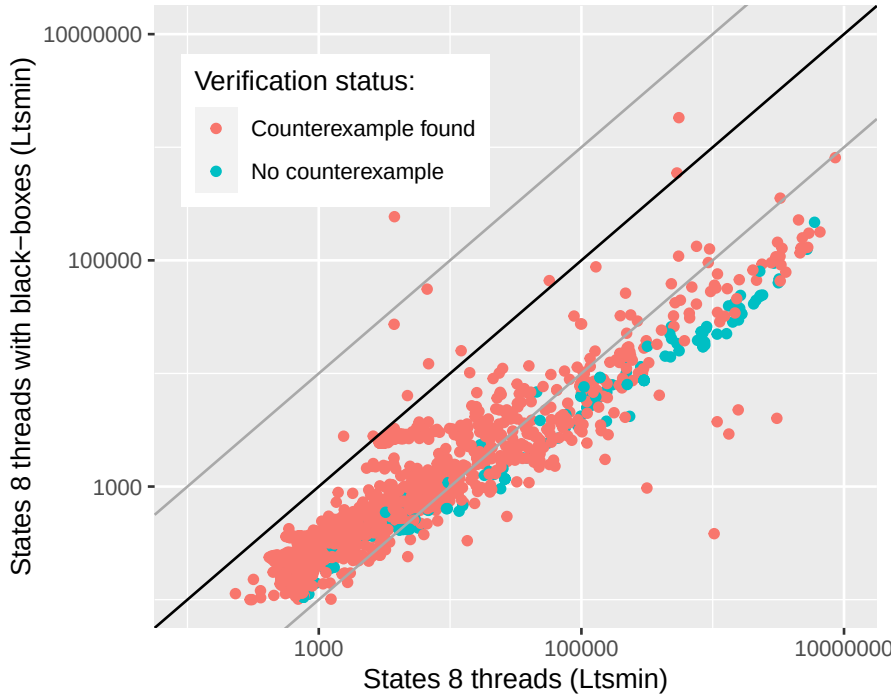
Benchmark: Spot



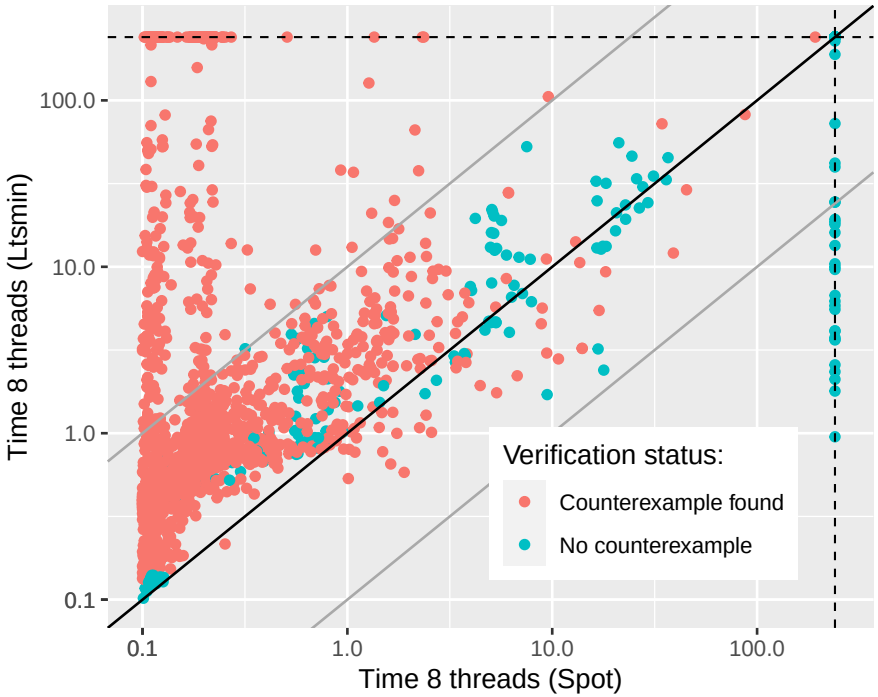


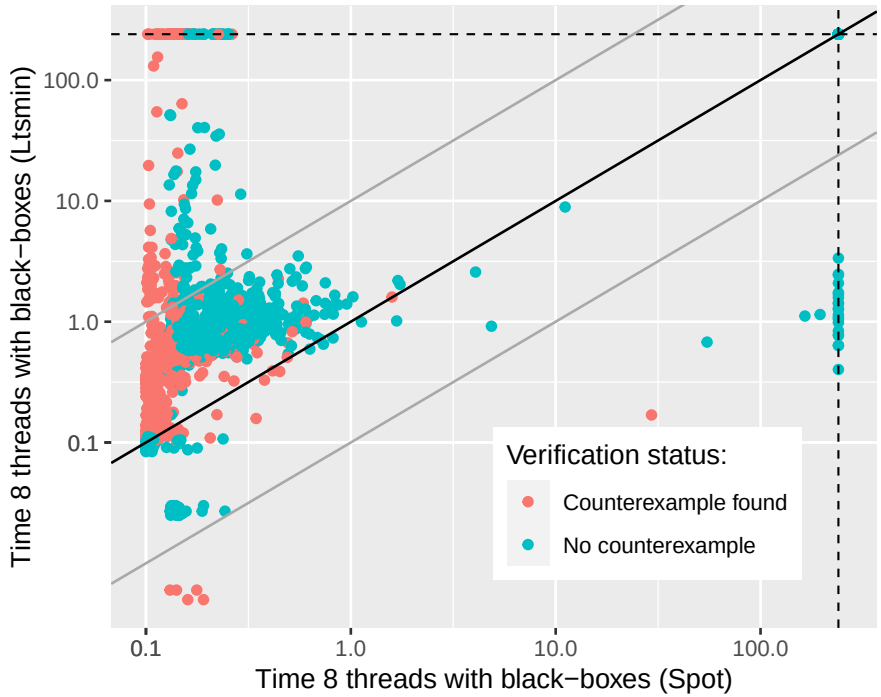
Benchmark: LTSmin





Benchmark: Spot vs. LTSmin

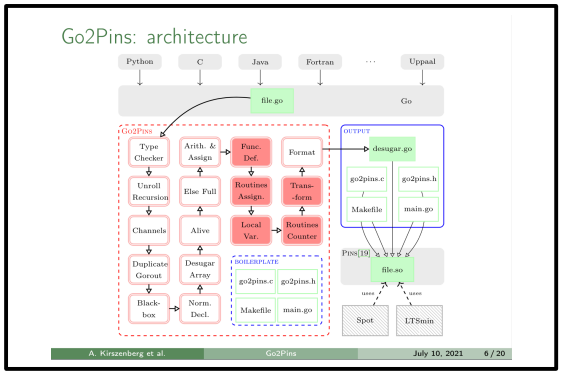




Future work

- Support more types
- Support Partial Order Reductions
- Study the relation between black-boxes and POR
- Finer blackboxes
- Check the fairness of the Go scheduler

Questions?


Go2Pins: architecture
Python
C
Java
Fortran
Uppaal
file.go
Go
Type Checker
Arith. & Assign
Func. Def.
Format
Unroll Recursion
Else Full
Routines Assign.
Trans-form
Channels
Alive
Local Var.
Routines Counter
Duplicate Gorout
Desugar Array
Black-box
Norm. Decl.
BOILERPLATE
go2pins.c
go2pins.h
Makefile
main.go
OUTPUT
desugar.go
Pins[19]
file.so
Spot
LTSmin
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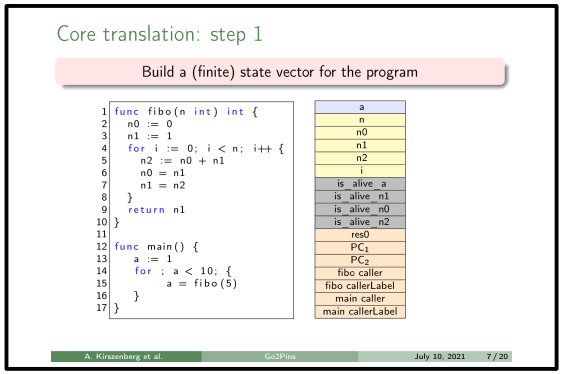
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a
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n0
n1
n2
i
is_alive_a
is_alive_n1
is_alive_n0
is_alive_n2
res0
PC1
PC2
fibo caller
fibo callerLabel
main caller
main callerLabel
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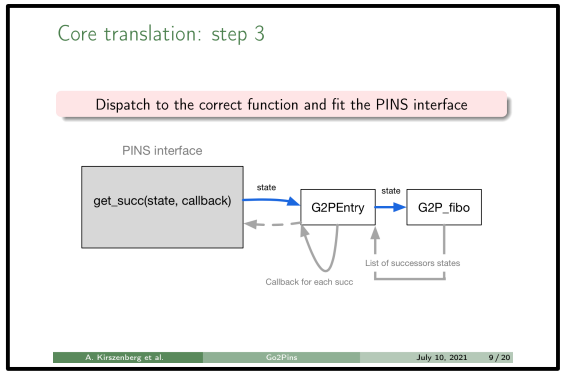
Core translation: step 3
Dispatch to the correct function and fit the PINS interface
PINS interface
get_succ(state, callback)
state
G2PEntry
state
G2P_fibo
List of successors states
Callback for each succ
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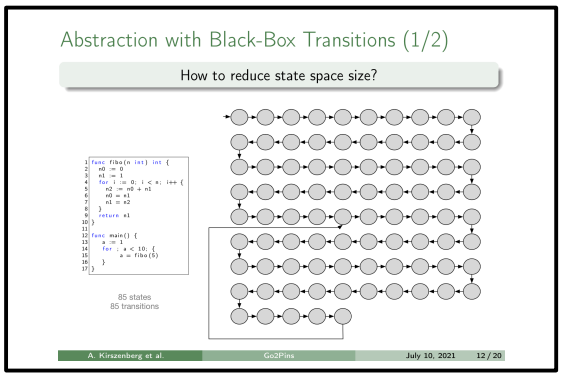
Abstraction with Black-Box Transitions (1/2)
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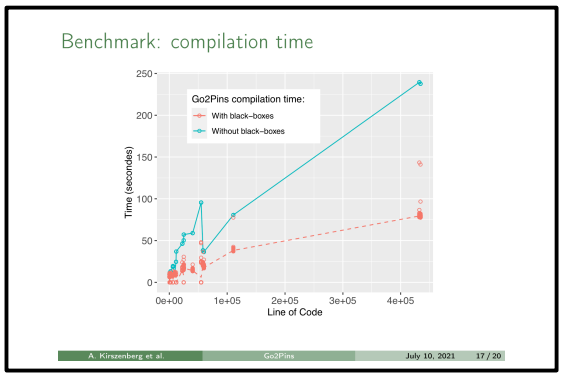
Benchmark: compilation time
Go2Pins compilation time:
With black-boxes
Without black-boxes
Time (seconds)
Line of Code
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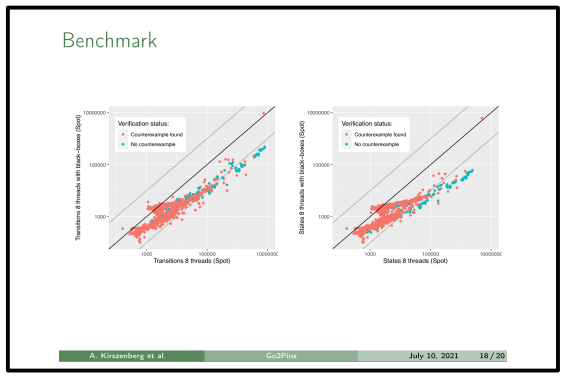
Benchmark
Verification status:
Counterexample found
No counterexample
Transitions 8 threads (Spot)
States 8 threads (Spot)
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