An Programming Language with Fixed-Logical Execution Time Semantics for Real-time Embedded Systems

embedded systems perspectives and visions

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More info: www-cad.eecs.berkeley.edu/~xgiotto

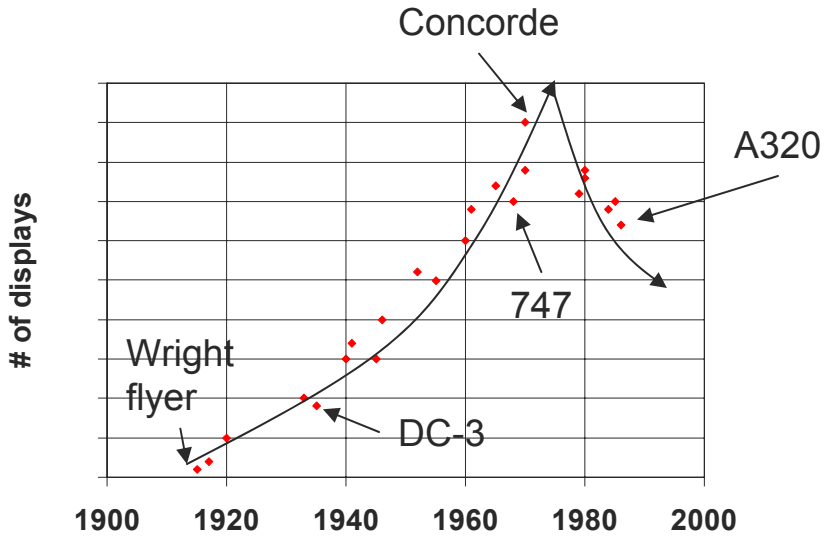
Motivation

- E**x**tending Giotto semantics for event-triggered systems
  - Giotto is purely time-triggered
- A structured programming for E code
  - Giotto generates only single-triggered E code (triggers only a timer)
- Functionality part of the Language
  - Single stand-alone language

Safety Critical Embedded Systems: Avionics

Number of displays in commercial airplane cockpits

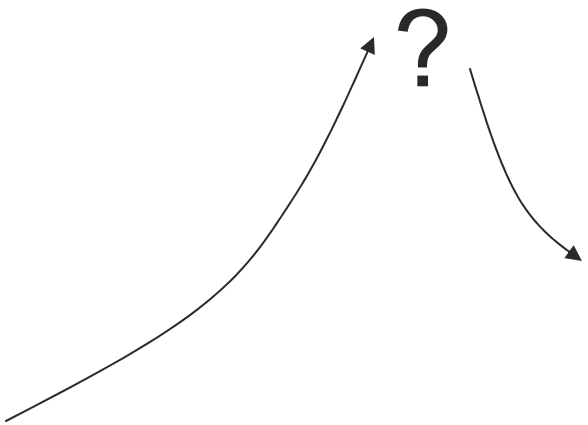
Complexity is to high, pilots unable to handle it!



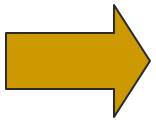
D.A. Norman, *The Invisible Computer*, MIT Press,1999

Embedded System Programming

- Number of language features
- Number of APIs



Complexity is to high, programmer is overloaded with information!



Domain Specific Languages

Domain Specific Languages

- Advantages:
  - “Ultimate abstraction” : capturing precisely the semantics of the application domain
- Disadvantages:
  - Design and implementation is difficult
  - Resist evolution

Robert L. Grass, *One Giant Step Backwards*, Communication of the ACM, 46(5), pp 21-23, 2003

Domain of the xGiotto Language

- Driven by interaction with environment
  - The environment dictates the speed
- Limited resources
  - The hardware imposes constraints
- Reliability
- Hard real-time constraints

The xGiotto Compiler

Similar to RISC/CISC situation:

> "Something to keep in mind while reading the paper was how lousy the compilers were of that generation. C programmers had to write the word register next to variables to try to get compilers to use registers. As a former Berkeley Ph.D. who started a small computer company said later, "people would accept any piece of junk you gave them, as long as the code worked." Part of the reason was simply the speed of processors and the size of memory, as programmers had limited patience on how long they were willing to wait for compilers."

David A. Patterson and Carlo H. Séquin. *Retrospective on RISC I. 25 years of the international symposia on Computer architecture (selected papers)* , 1998, p.25

Outline

- Giotto key-aspects
- xGiotto key-aspects
  - Fixed Logical Execution Time
  - Semantics
  - Conference Program
- Analysis
  - Environment assumptions
  - Race conditions detection
  - Time Safety
  - Program Classes
- Implementation
- Future Research Perspectives
- Related Work
- Questions

Giotto Key-Aspects

Platform Independence ensures Predictability

Time Determinism:

The Giotto compiler chooses for a given platform a platform timeline that is value equivalent to the environment timeline defined by the Giotto semantics.

implies

Value Determinism:

For a given time-triggered sequence of sensor readings, the corresponding time-triggered sequence of actuator settings is uniquely determined (i.e., there are no race conditions).

xGiotto Key-Aspects

Platform Independence ensures Predictability

Event Determinism:

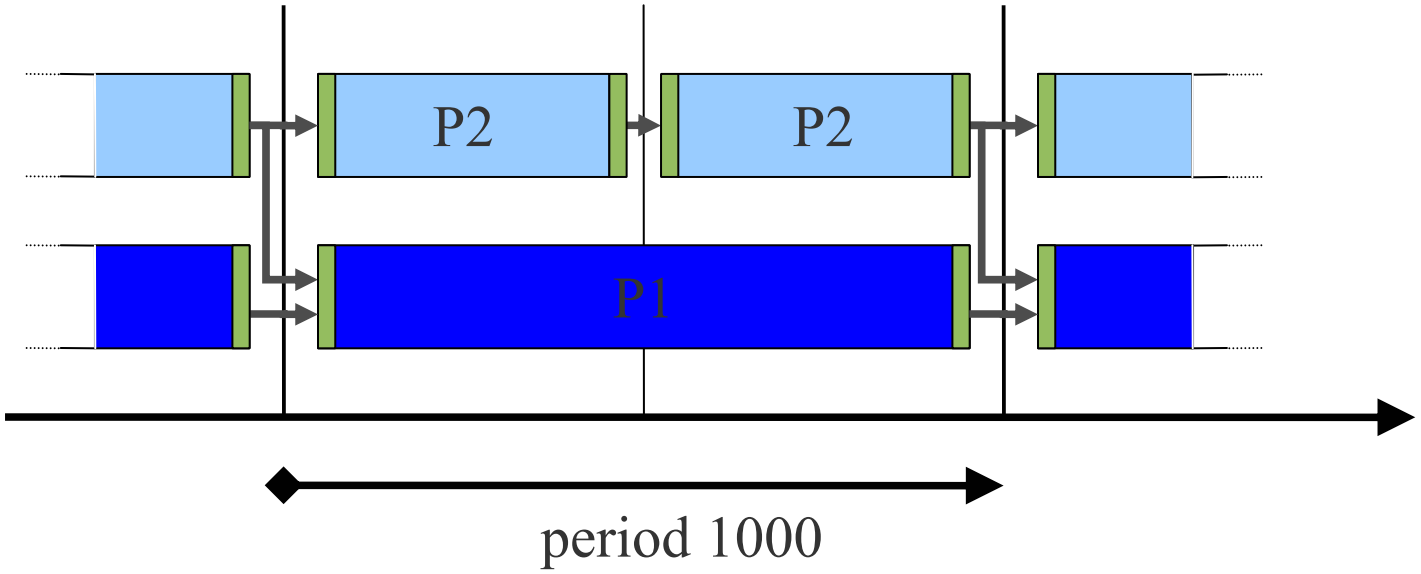
The xGiotto compiler chooses for a given platform a platform timeline that is value equivalent to the environment timeline defined by the xGiotto semantics.

implies

Value Determinism:

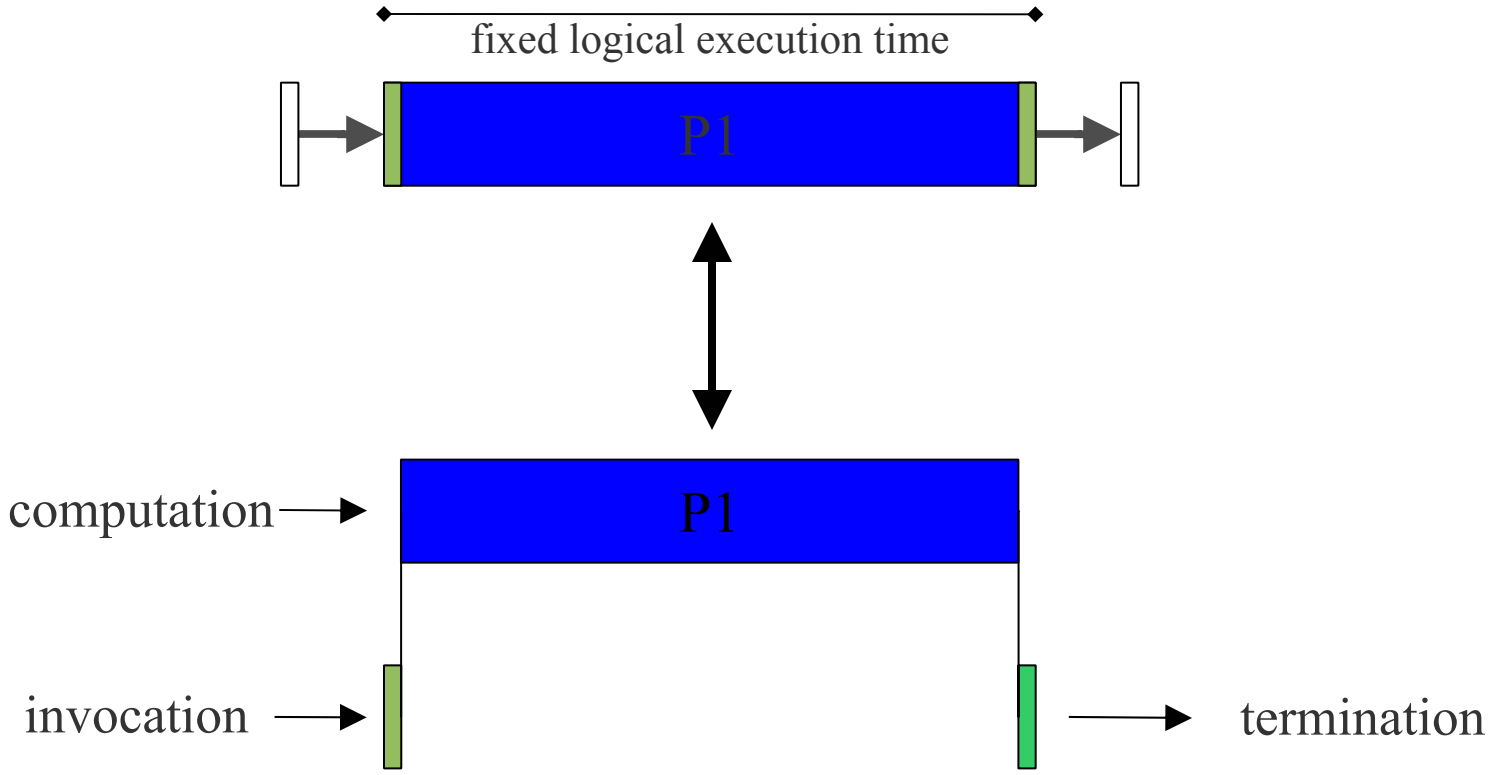
For a given event-triggered sequence, the corresponding sequence of port values is uniquely determined

Giotto Timeline

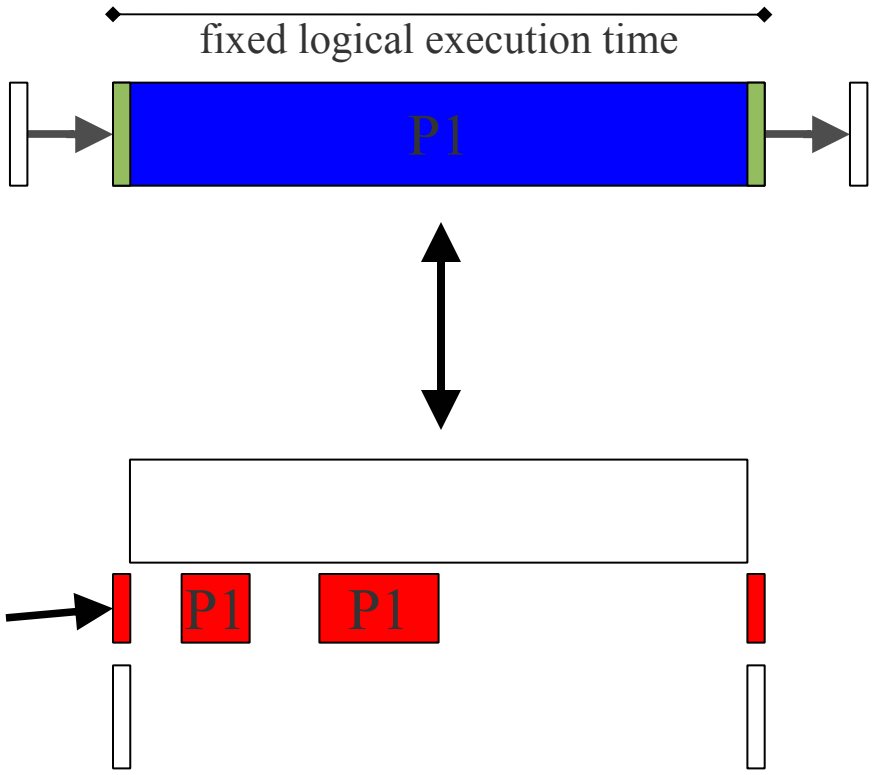



```
mode normal() period 1000 {
    taskfreq 1 do P1(getP1in);
    taskfreq 2 do P2(getP2in);
  }
```

Fixed Logical Execution Time

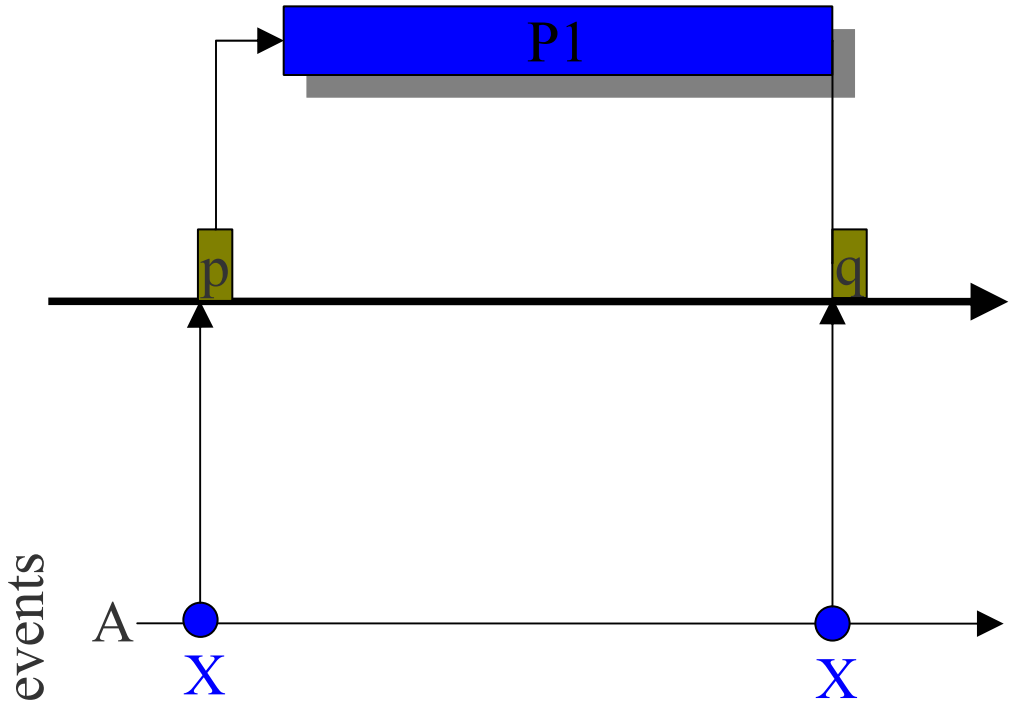


Fixed Logical Execution Time



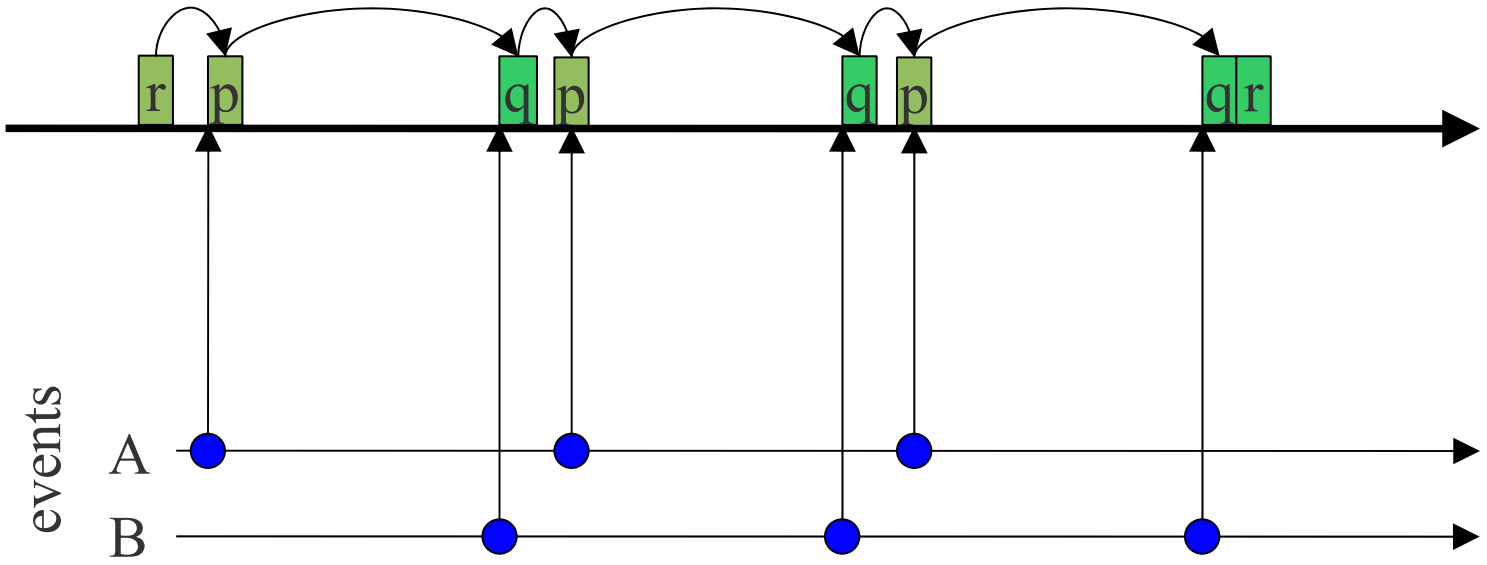
The platform will allocate the computation

xGiotto
Fixed Logical Execution Time




```
PORT
    INTEGER p;
    INTEGER q;

EVENT
    INTEGER A AT X;

TASK P1(INTEGER a)
      OUTPUT (INTEGER b){
    b := b + 1;
}

TIMING T1() {
    P1(p)(q)[A];
}

{[A]T1();}
```

xGiotto Timeline



xGiotto Semantics

- Task Invocation:
  - t(pi) (p0)[E]: When E arrives p0 is written with the evaluation of t (on the value of pi).
- Events:
  - External events: generated externally by an interrupt.
  - Completion events: internal events generated at the end of a task execution.
  - Combined events: concatenation of event expressions.
- Reaction: (event, action)
  - Timing reactions: action is an invocation of a block of xGiotto code.
  - Deactivation reactions: action is removal of a timing reaction.
  - Termination reactions: action is updating of output ports with the evaluation of task.

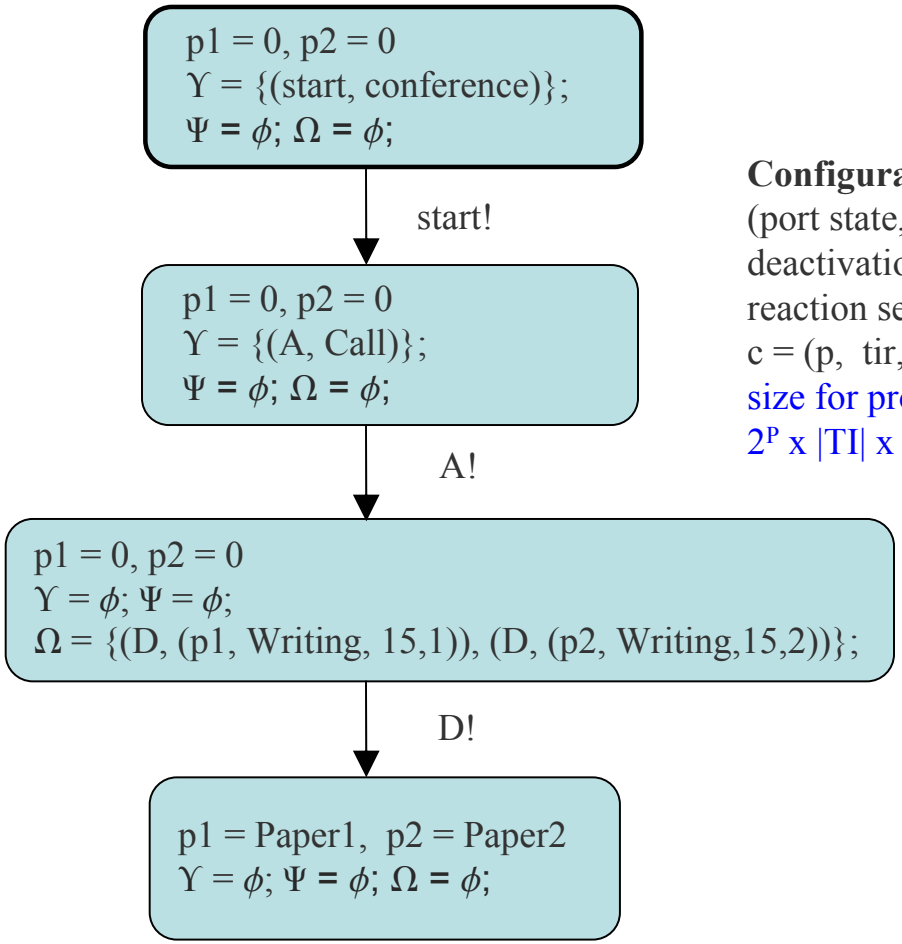
Example: A Conference

```
PROGRAM conference {

 TYPE paper ARRAY 15 OF INTEGER;
 PORT
    paper p1;
    paper p2;
 EVENT
   INTEGER A AT CallForPaper;
   INTEGER D AT Deadline;

 TASK Writing (INTEGER pages, INTEGER seed)
    OUTPUT (paper p) VAR (INTEGER j) {
    j = 1;
    while (j < pages) {p[j] = MakeScience(seed); j++;}
 }

 TIMING Call() {
   Writing(15, 1)(p1)[D];
   Writing(15, 2)(p2)[D];
   [A]Call();
 }

 {[A]Call()}
}
```

Analysis

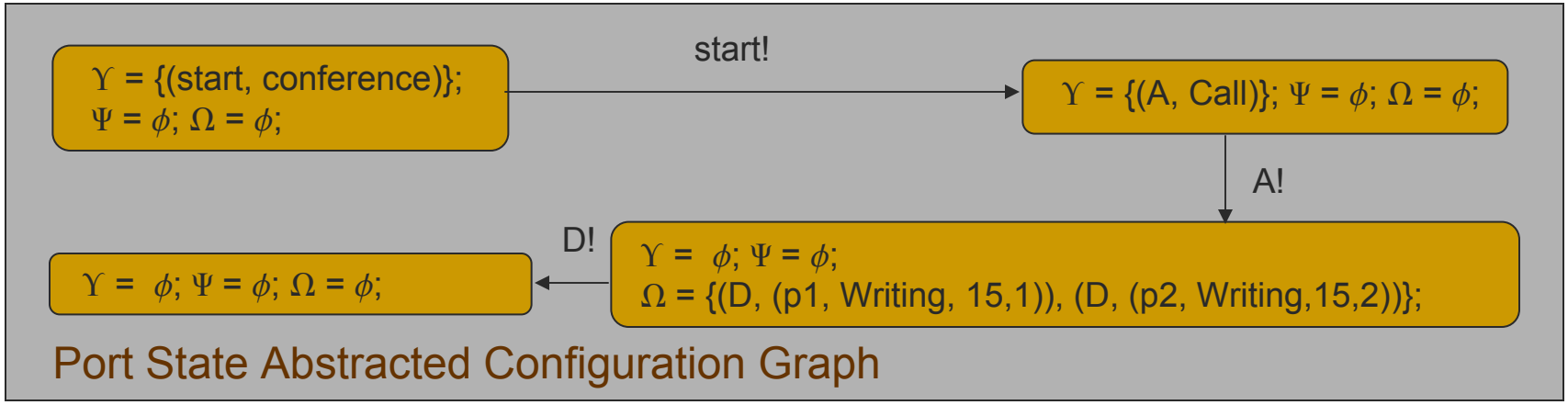
- Configuration Graph
- Port Abstract Reaction Graph
- Termination Reaction Graph
  - Port Update Conflicts
  - Adding Environment Assumption
  - Time Safety

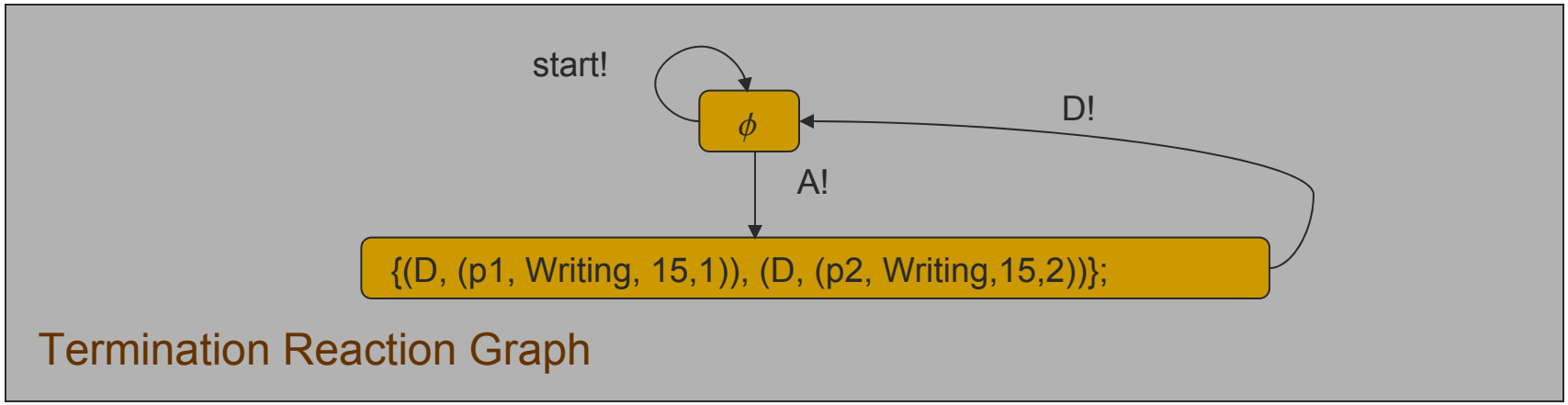
Configuration Graph



Configuration:
(port state, ϒ timing reaction set, Ψ deactivation reaction set, termination reaction set)
c = (p, tir, der, ter)
size for propositional Program:
2^P x |TI| x |U| x 2^PP!|T||E|

xGiotto Graph Abstractions





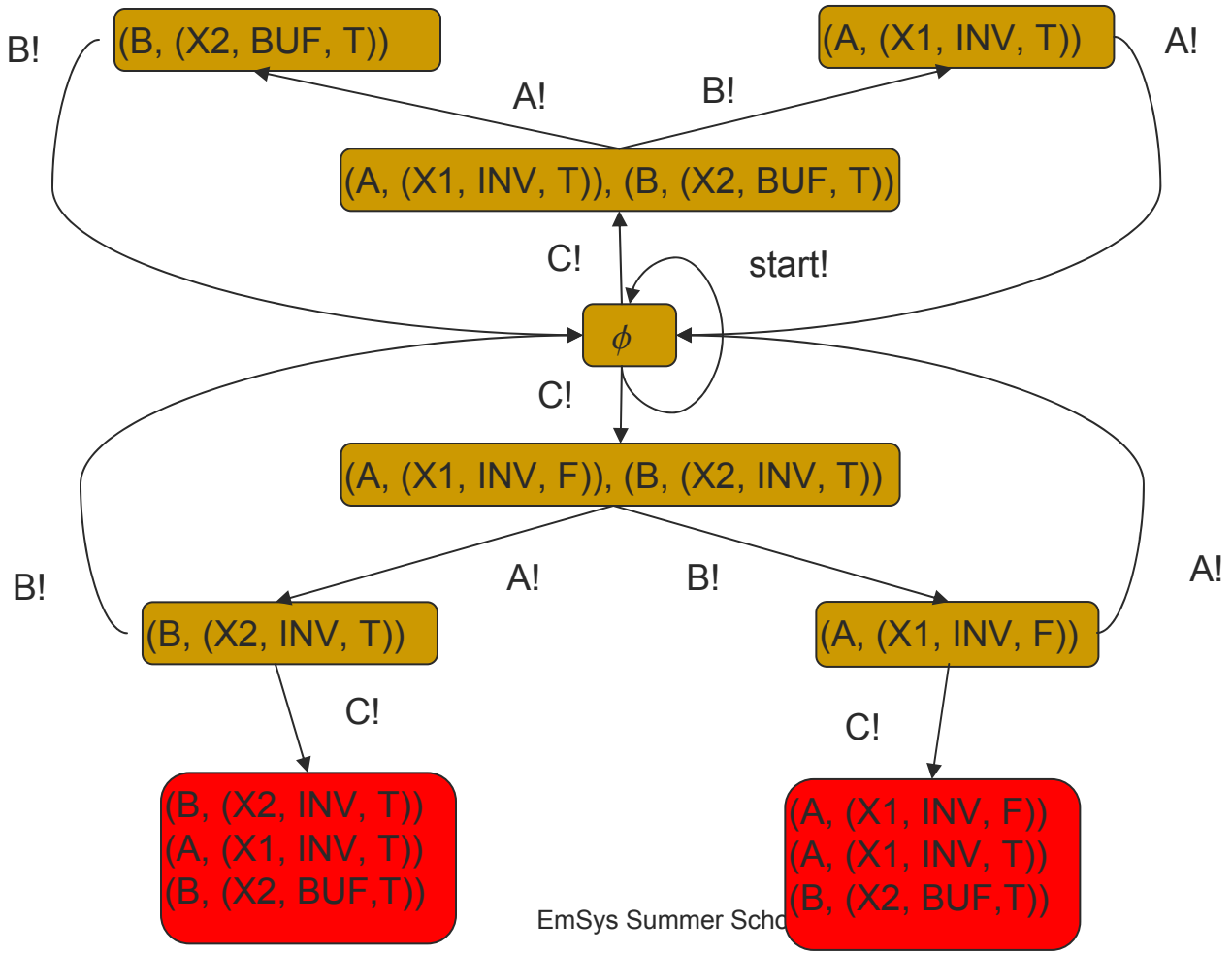
Race Condition Detection (Port Update Conflict)

- Importance
  - A port may be updated by multiple values at an instance
- Problem Definition
  - Given a xGiotto program, the port update conflict verification returns the answer YES if the program is conflict free, NO otherwise
- Hardness
  - The problem is PSPACE-complete for propositional xGiotto program
- Analysis
  - Search on Termination Reaction Graph

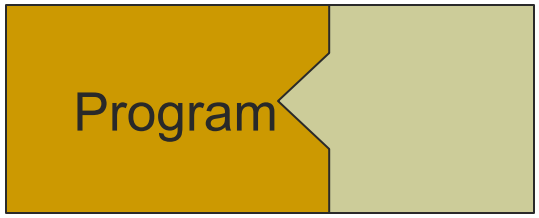
Port Update Conflict Example

```
PROGRAM Example {

PORT
    BOOLEAN X1;
    BOOLEAN X2;
 EVENT
   BOOLEAN A AT interrupt1;
   BOOLEAN B AT interrupt2;
   BOOLEAN C AT interrupt3;

 TASK Inverter (BOOLEAN in) OUTPUT (BOOLEAN out) {out = !in; }
 TASK Buffer (BOOLEAN in) OUTPUT (BOOLEAN out) {out = in;}

 TIMING T1() {
   Inverter(FALSE)(X1)[A];
   Inverter(TRUE)(X2)[B];
   [C]T2();
 }
 TIMING T2() {
   Inverter(TRUE)(X1)[A];
   Buffer(TRUE)(X2)[B];
   [C]T1();
 }
 {[C]T1();}
}
```

Port Update Conflict

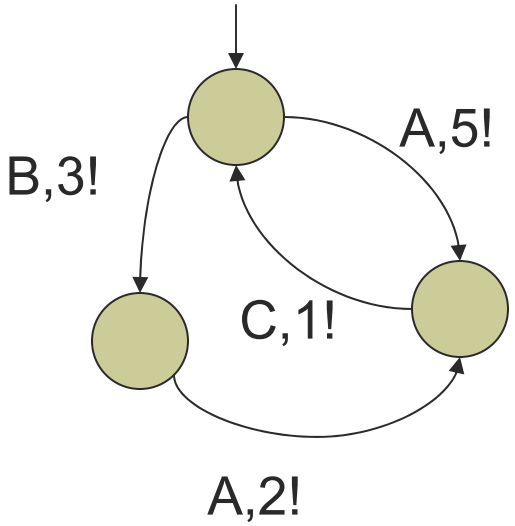


Environment Assumption



Reduction of
Termination Reaction Graph
Adding time information for
Schedulability

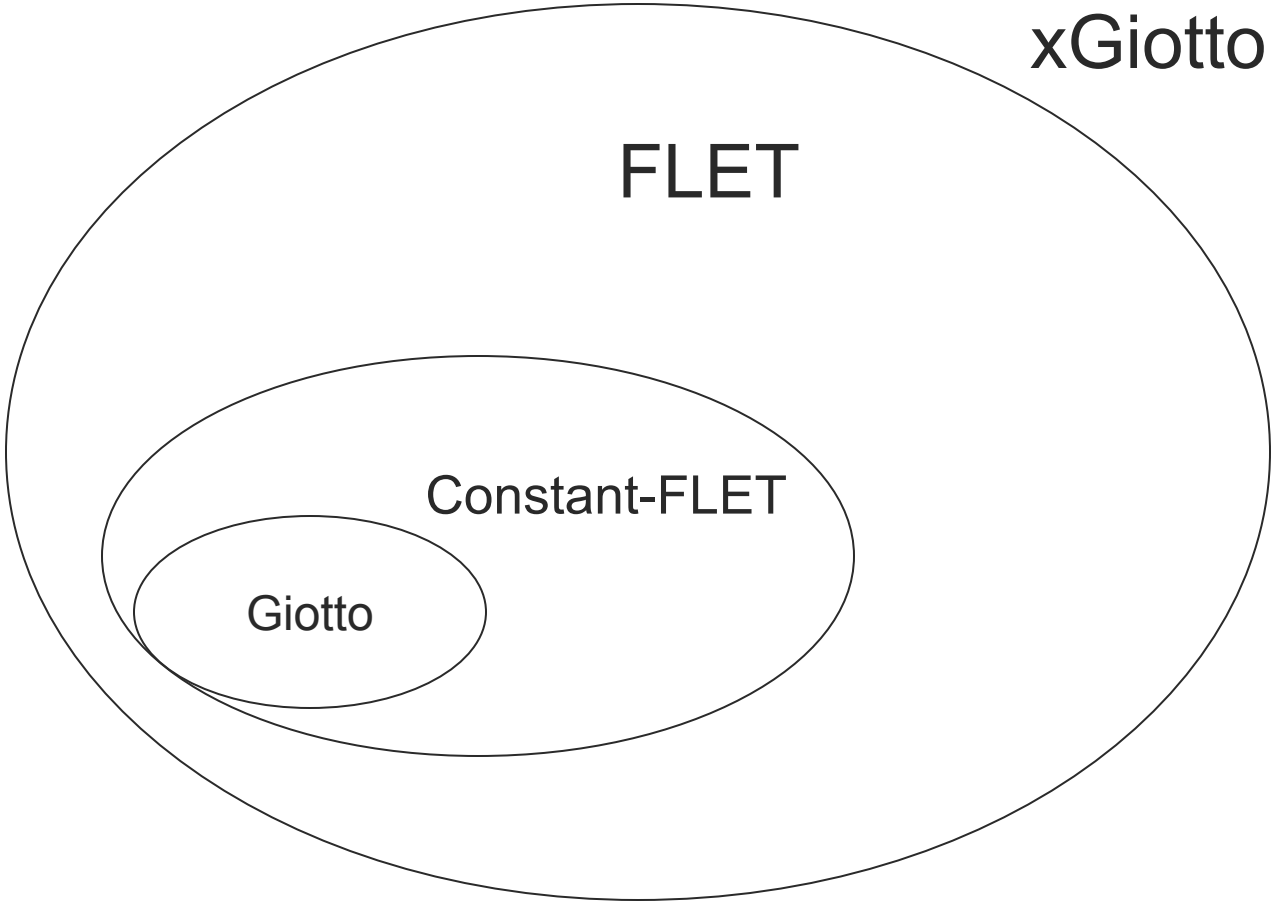
Event time Automaton:
Arrival of events and their time
(simplified version of
Alur-Dill Timed Automaton,
i.e. one single clock, integer time)



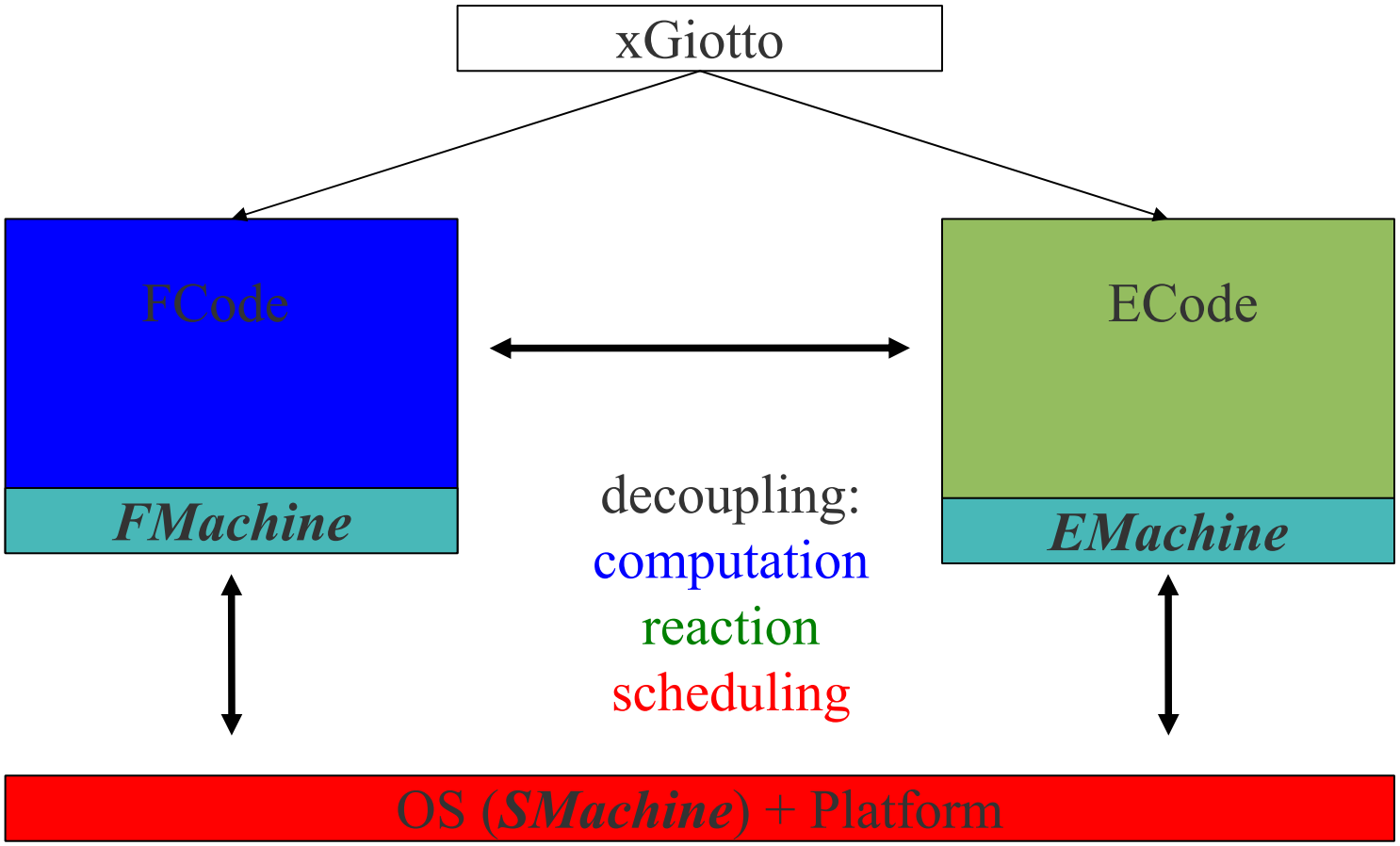
Time Safety

- xGiotto: EXPTIME — All
- Constant-FLET: P — Acyclic Deadline Monotonic
- Giotto: P — Earliest Deadline First

xGiotto Program Classes



Implementation



Related Works

- Giotto
- Esterel
- nesC (TinyOS)

  [The nesC Language: A Holistic Approach to Networked Embedded Systems, D. Gay, P. Levis, R. von Behren, M. Welsh, E. Brewer, D. Culler. In *Proceedings of Programming Language Design and Implementation (PLDI) 2003*, June 2003.]

Future Research Opportunities

- More freedom for platform-dependent optimizations [LCTES03 papers!]
  - Dynamic Voltage Scaling (DVS)
  - Code size/speed/power
- Anytime scheduler

  [Real-Time Adaptive Resource Management for Advanced Avionics
  M. Agrawal, D. Cofer, and T. Samad , IEEE Control System Magazine, Feb 2003]
  - Task able to deliver partial, but valid outputs

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