Coordination of Synchronous Components with Time Triggered Programming

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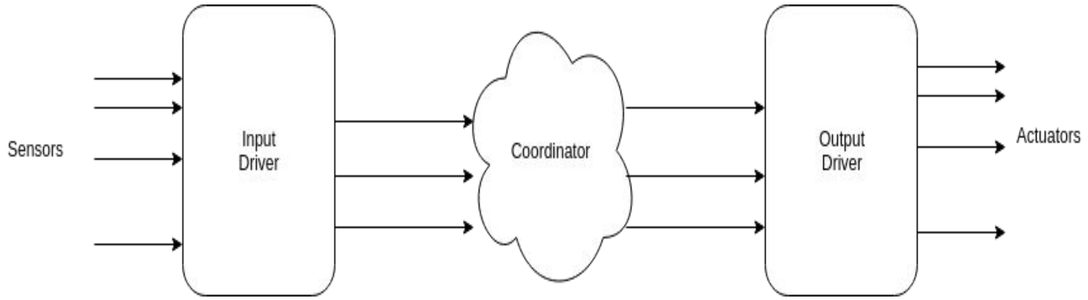
Big Picture

- Synchronous languages lustre/Heptagon is good for **coordination** of embedded systems



- But they follow **Synchrony Hypothesis:-**
  - Computation and communication takes negligible time
- So it fails for **time intensive** task

Big Picture

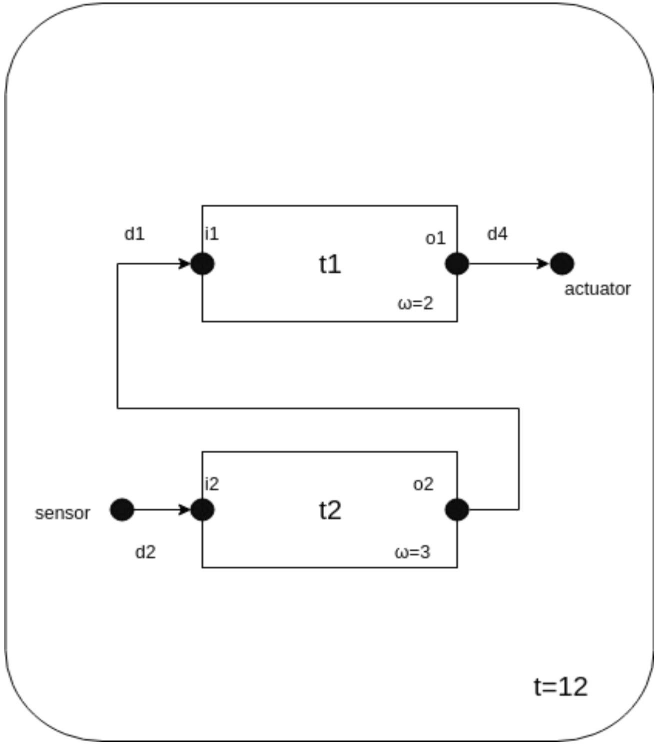
- To solve this we combined **Heptagon components** with a **Time Triggered Language** TTProg inspired by Giotto
    - Thomas A. Henzinger, Benjamin Horowitz and Christoph M. Kirsch,"**Giotto**: A Time-triggered Language for Embedded Programming", in Proceedings of the IEEE, vol. 91. IEEE, 2003

    - **Heptagon** language: Gwenaël Delaval, Hervé Marchand, Marc Pouzet, Eric Rutten

- We call this **High level language** as **TTProg[Heptagon],** this allow components whose execution takes time
- We retain some of advantages of both

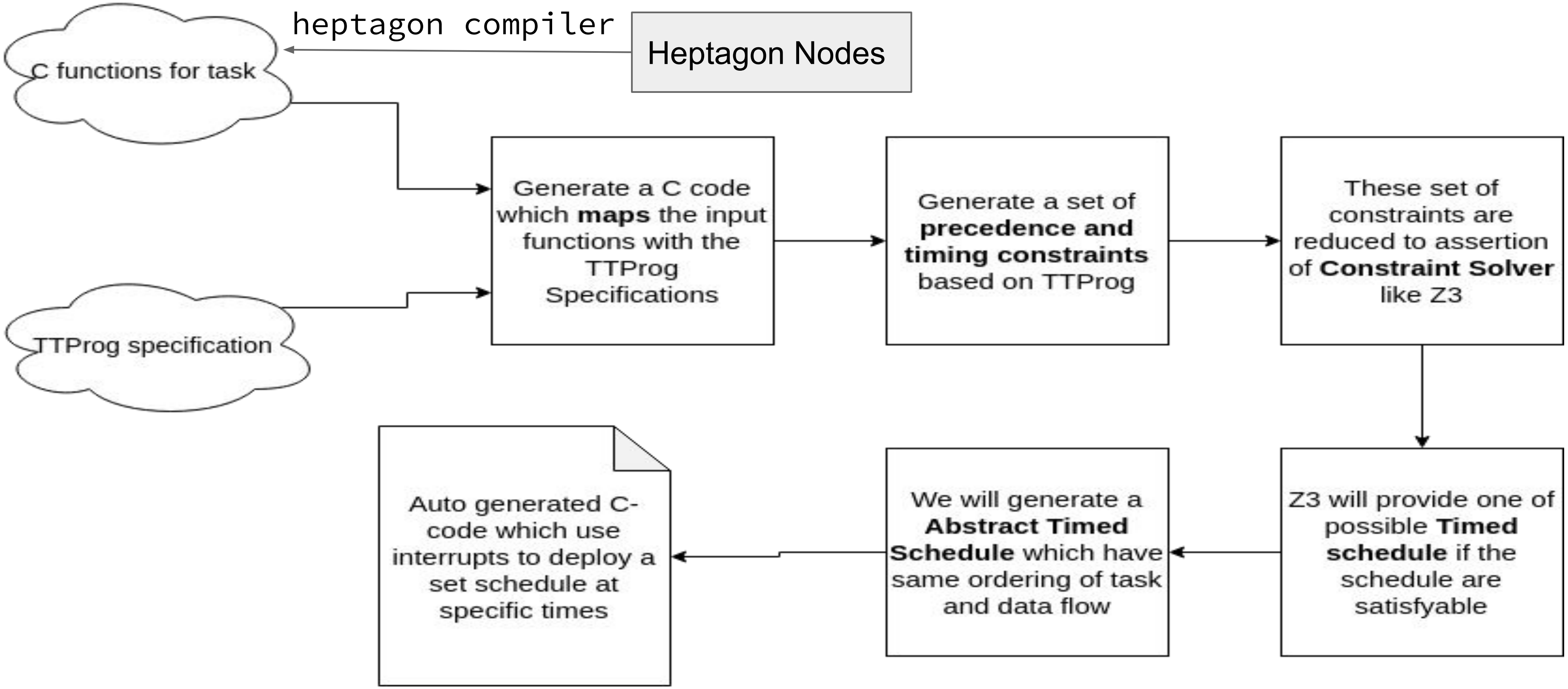
Big Picture

- The components will be combined in deterministic fashion and may have data dependencies
- It will also have a set of timing constraints



What we did

We built a multiphase automated compiler which does the following:-



Motivation

- We implement Static Scheduling
- It is a bare metal implementation
- Does not require any RTOS or Context Switching
- Deterministic and memory will be statically initialized
- Very efficiently executable code
- It will give extreme speed to tight application

Literature Surveys

Synchronous Programming Languages

- State Charts
- Lustre
- Heptagon

Asynchronous Programming Languages

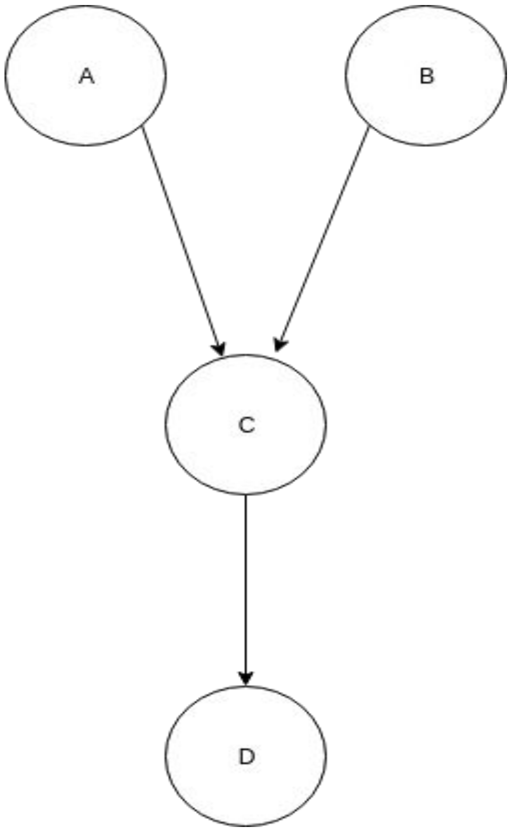
- Linda

Time Triggered Programming Languages

- Giotto

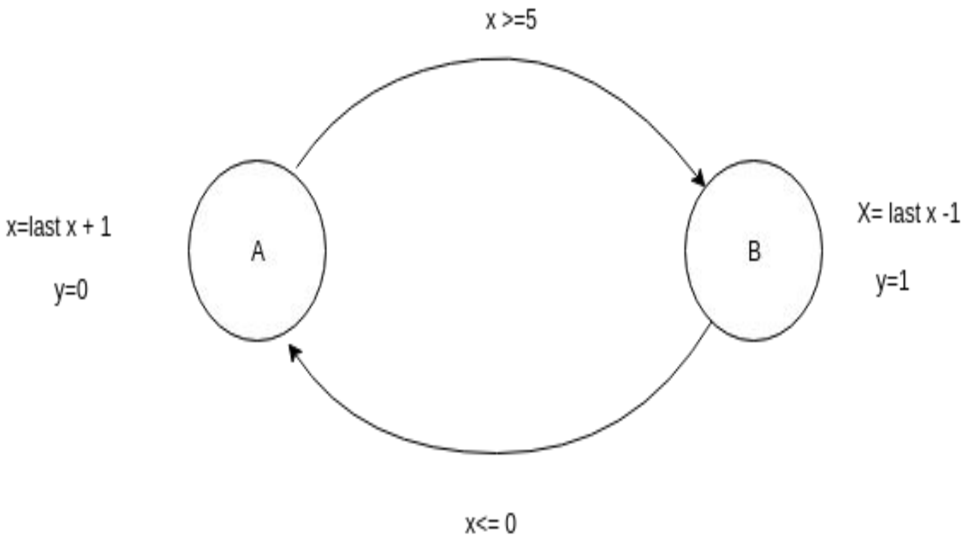
Heptagon

- It is a synchronous dataflow language
- Declarative language
- Very useful in designing reactive systems
- For each step cycle the node will read the value from input stream and write the value as output stream

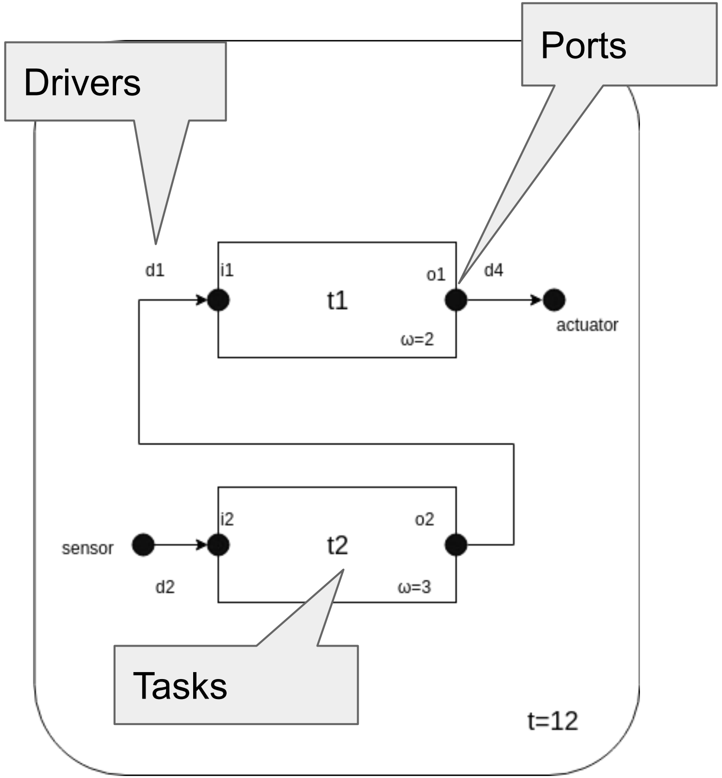


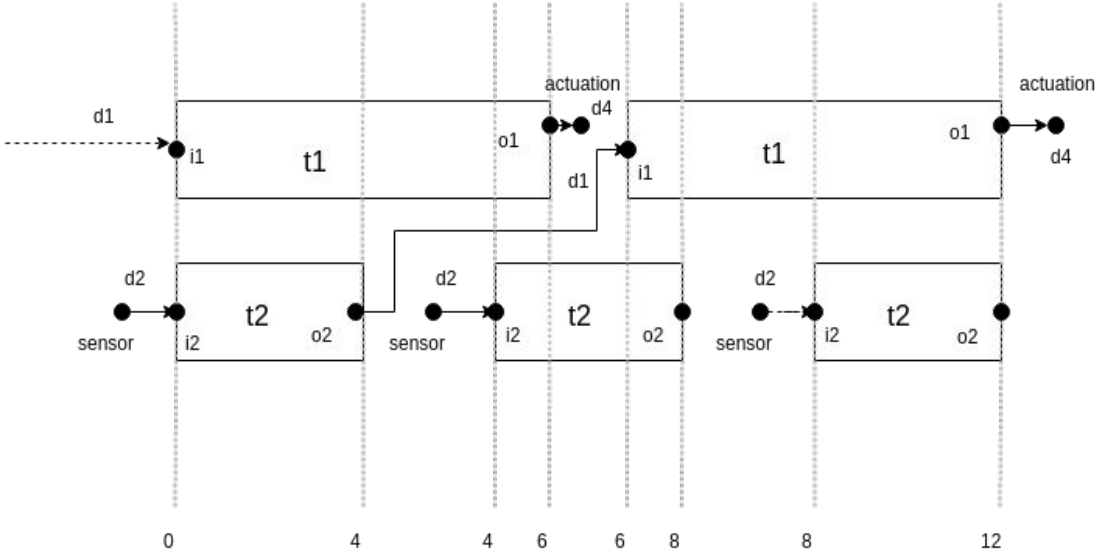
Heptagon Automata

```
node atm() returns(z,y:int)
var last x: int =0;
let
    z=x;
    automaton
        state A
            do x= last x +1; y=0
            until x>=5 then B
        state B
            do x= last x -1;y=1
            until x<=0 then A
    end
tel
```



TTProg Inspired by Giotto

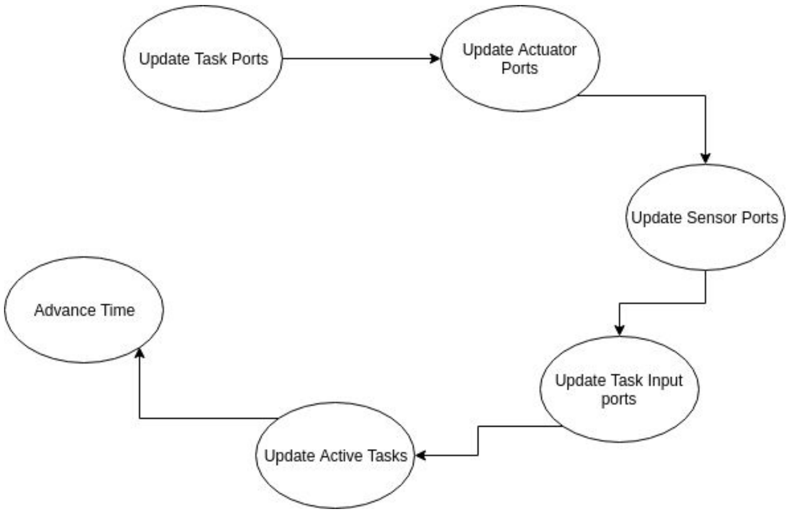


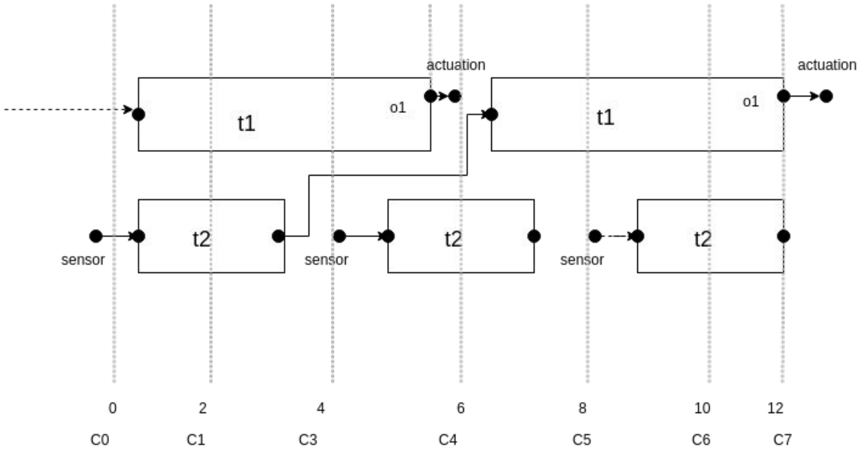


TTProg Configuration and Micro Steps

$$C = (m, \delta, v, \sigma_{active}, \tau)$$

$$C_{update} = \frac{T}{\omega_{LCM}}$$

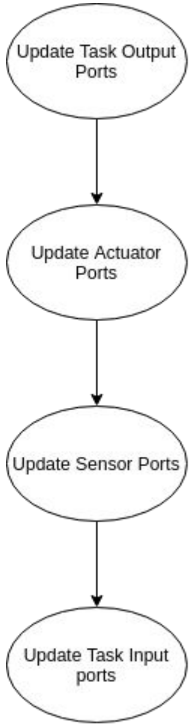




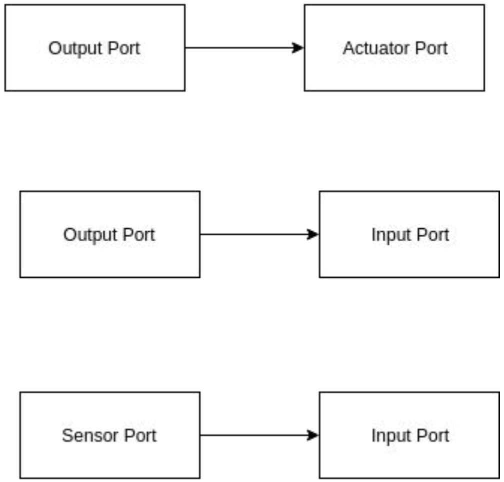
TTProg[Heptagon]

Giotto Tasks		Heptagon Nodes
task name (t)	⟺	node name
Input Ports	⟺	node inputs
Output Ports	⟺	node outputs
function (f)	⟺	step function

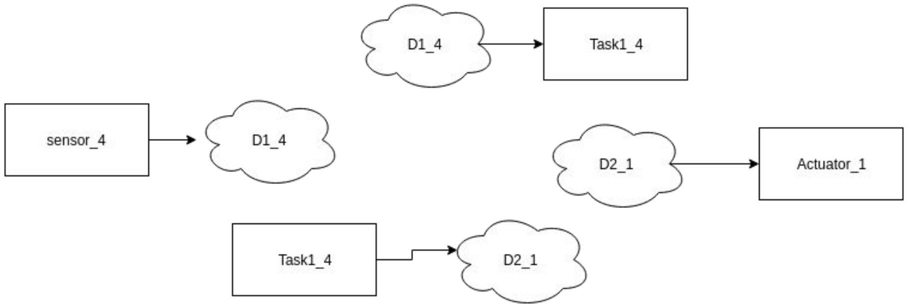
TTProg Data Flow



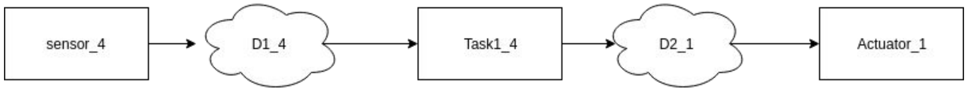
Giotto Micro Steps



Micro Steps Dependencies

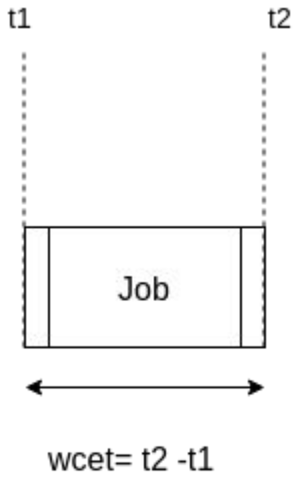


Individual Constraints



Data Flow

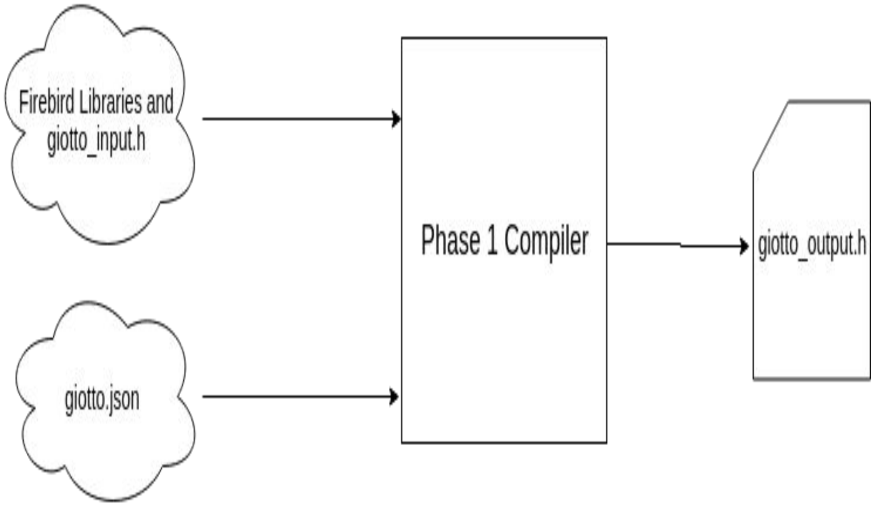
WCET



micros(): Number of microseconds since current execution of program

```
t1=micros();
f1(1);
t2=micros();
time=(t2-t1);
```

Phase 1 compiler



- All ports as global variable
- void functions for all the task generated and mapped with input functions
- Port values passed to these functions as specified
- Output of function is obtained by call by reference

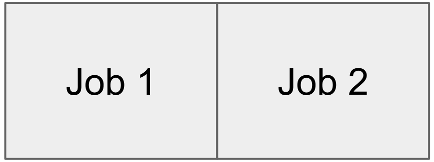
Phase 2 compiler-Serialization Constraints

$job_1, job_2 \in \{Drivers, Task\}$

$job_1 != job_2$

Constraints will be of form:

$job_1 + wcet_1 <= job_2 || job_2 + wcet_2 <= job_1$



Phase 2 compiler-Timing Constraints

Actuator

Lower Bound:

$$actuation_i >= \frac{ModePeriod}{ActuatorFrequency} * i - jitter$$

Upper Bound:

$$actuation_i + wcet <= \frac{ModePeriod}{ActuatorFrequency} * i$$

Sensor

Lower Bound:

$$input\_tn_i >= \frac{ModePeriod}{TaskNFrequency} * i$$

Upper Bound:

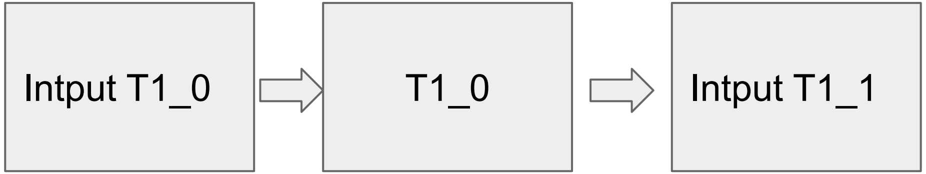
$$input\_tn_i + wcet <= \frac{ModePeriod}{TaskNFrequency} * i + jitter$$

Phase 2 compiler-Precedence Constraints

Driver-Task

$$input\_tn_i + wcet <= tn_i \text{ , where wcet is for the driver}$$

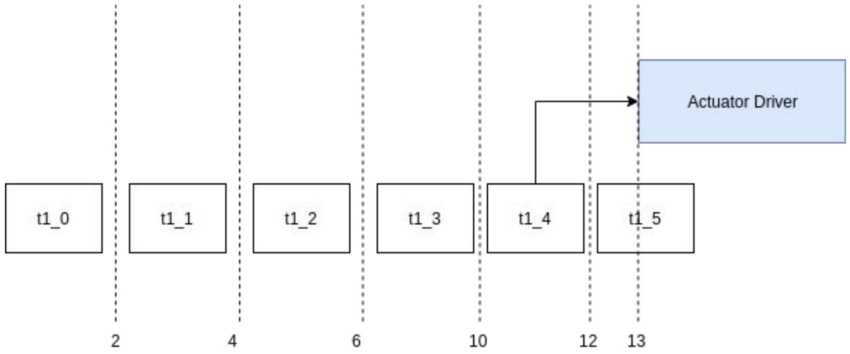
$$tn_i + wcet <= input\_tn_{i+1} \text{ , where wcet is for the task}$$



Phase 2 compiler-Precedence Constraints

Task-Actuator

$$j = \frac{LogicalStartTimeOfActuation_i}{LogicalTimePeriodOft1}$$



Actuation i occur after task instance j

$$t1_j + wcet_{task} <= actuation_i$$

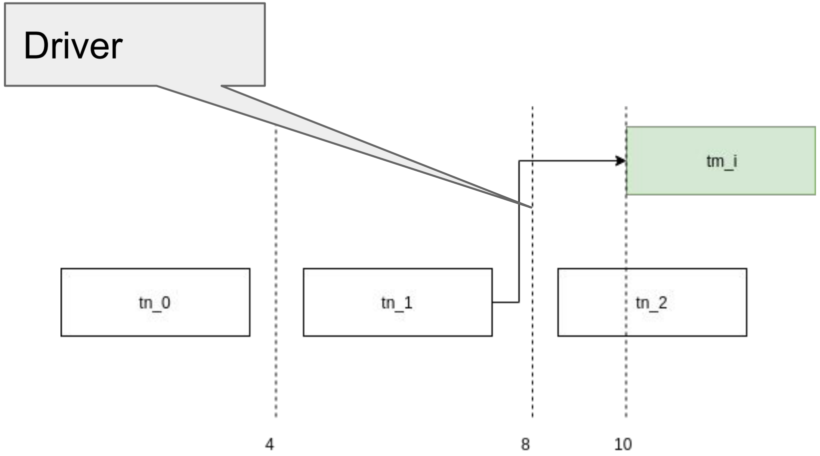
Task instance j+1 should occur after the actuation

$$actuation_i + wcet_{act} <= t1_{j+1}$$

Phase 2 compiler-Precedence Constraints

Task-Driver

$$j = \frac{LogicalStartTimeOft1_i}{LogicalTimePeriodOft2}$$



Instance i of t1 should occur after instance j of t2

$t2_j + wcet_{t2} <= input\_t1_i$

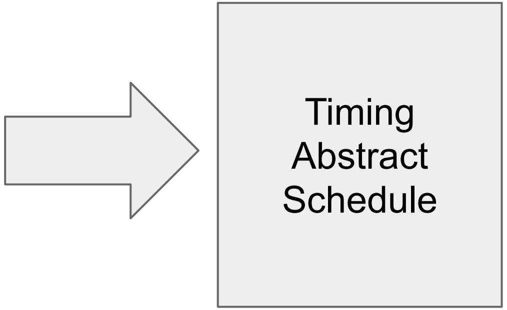
To make sure other instance of t2 run after input driver of $t1_i$

$input\_t1_i + wcet_{input\_t1} <= t2_{j+1}$

Phase 3 COmpiler

```
avais@avais-Lenovo-Z50-70:~/Documents/P
sat
[input_t2_2 = 8,
 input_t2_1 = 4,
 t1_update_0 = 9/20,
 t2_update_0 = 9/2,
 t1_1 = 19/4,
 t2_2 = 19/2,
 input_t1_0 = 0,
 actuation_1 = 11,
 input_t2_0 = 1/2,
 t1_0 = 1/4,
 t2_0 = 5/4,
 actuation_0 = 5,
 t2_update_1 = 37/4,
 t2_1 = 17/2,
 t1_update_1 = 6,
 t2_update_2 = 41/4,
 input_t1_1 = 1]
```

Timed Schedule



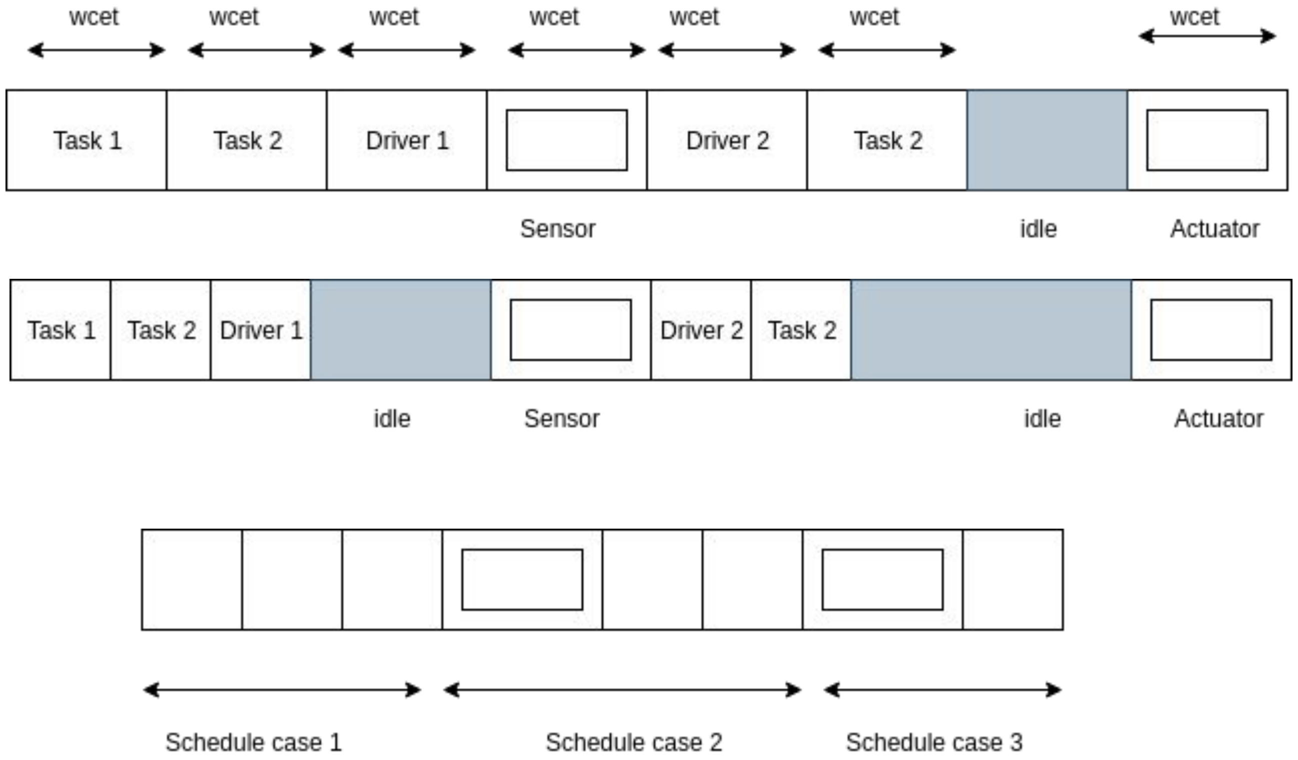

```
input_t1
t1
wait

input_t2=0.5
t2
input_t1
wait

input_t2=4
t2
wait

actuation
t1
wait

input_t1=8
t2
wait

actuation=11
```

Phase 3 COmpiler

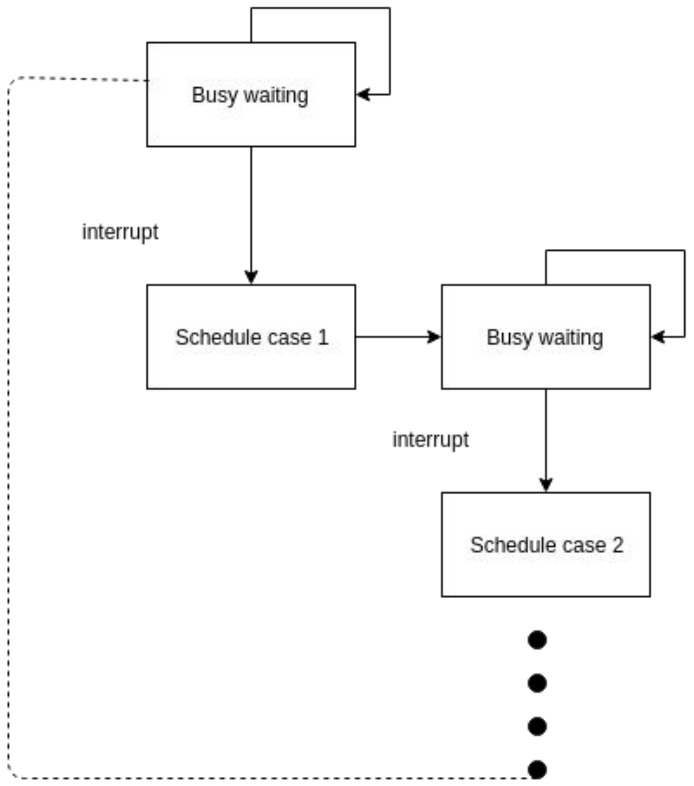
Initial Timed Schedule

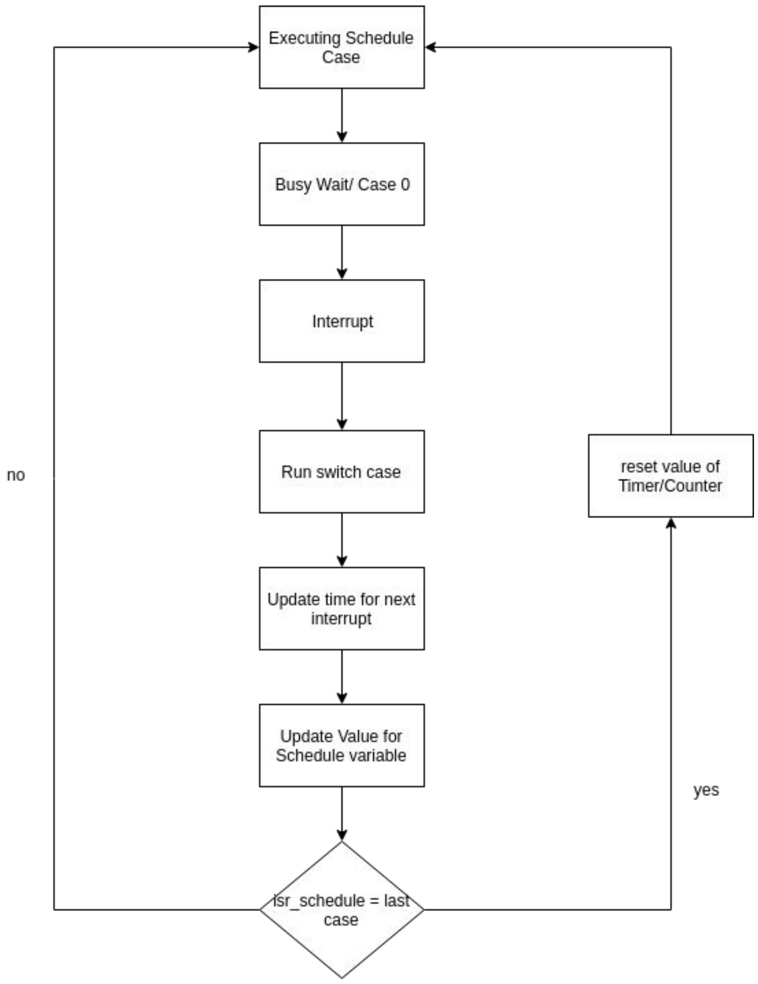
Equivalent Schedule

Schedule Breakup

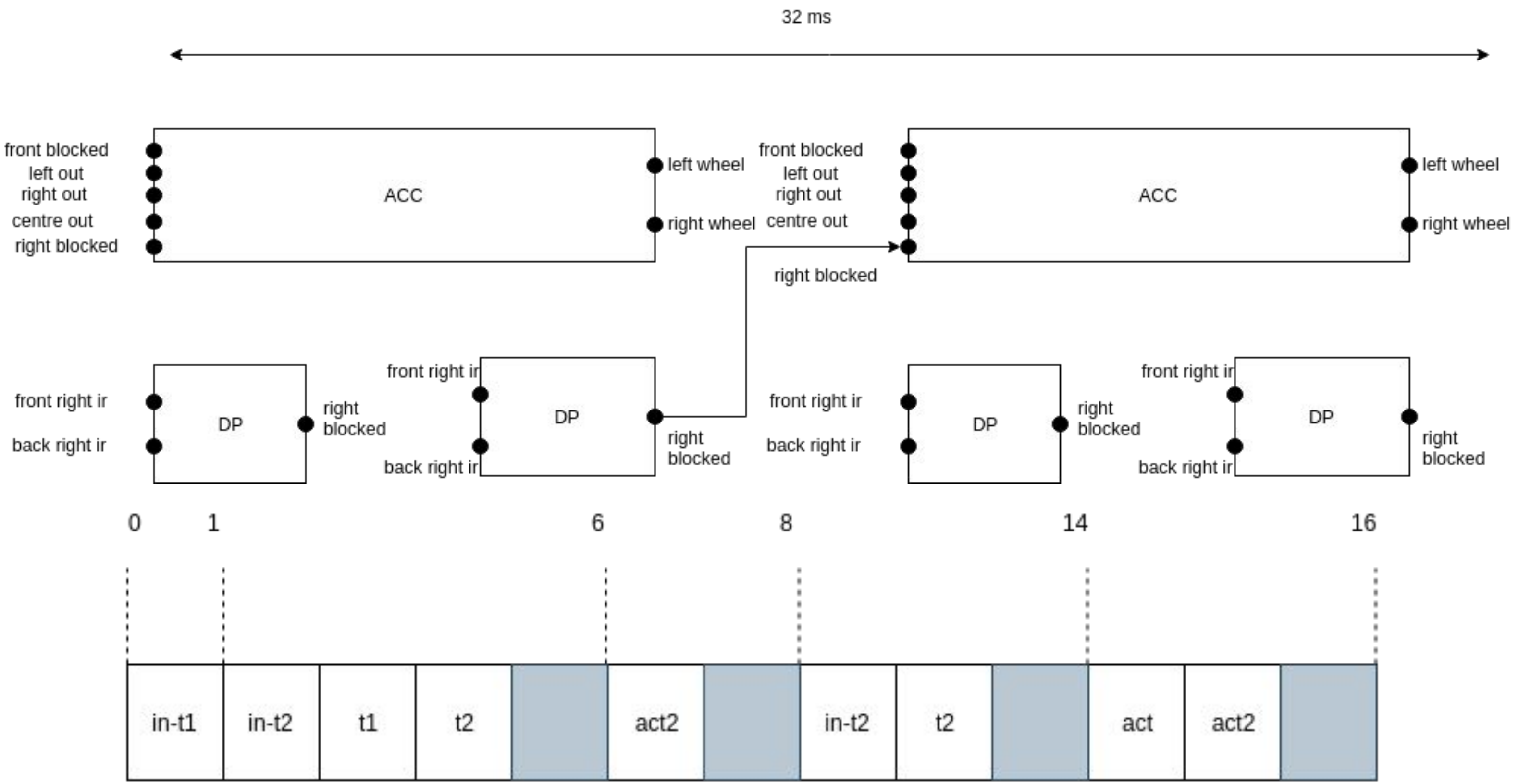


Phase 3 COmpiler





Case Study-Acc+detect parking



CONCLUSION

- We have successfully demonstrated the applicability of our TTProg[Heptagon] High Level Programming technique to robotics
- Architecture and processor independent technique
- WCET needs to be provided
- Static Scheduling
- Highly efficient code
- Deterministic Dataflow
- No context switching,memory allocation and RTOS required

Future WOrk

- Multiple modes
- Error handling in compiler
- Option to choose different processor prescaler
- Extend to multi processor systems
- Automatic technique to decompose large task to small task
- Needs to be applied to complex robot programming

References

I. Thomas A. Henzinger, Benjamin Horowitz and Christoph M. Kirsch,"Giotto: A Time-triggered Language for Embedded Programming", in Proceedings of the IEEE, vol. 91. IEEE, 2003

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V. Heptagon/BZR manual. 2017. URL : \url{http://heptagon.gforge.inria.fr/pub/heptagon-manual.pdf}