Harmonic clocks and how to infer them

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Disclamer

Work in progress...

Multiperiodic harmonic clocks

- Consider a particular set of clocks ($\subset$ N-synchronous clocks)
  - Strictly periodic
  - One activation per period

$\Rightarrow$ $0^k(10^{n-1})$, k is the *phase* and n the *period*

- Multiple harmonic periods
  - Integral ratio between periods
  - Synchronized start

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- Why are we considering this kind of clocks?
  - Frequently used for integration code
  - Property can be exploited to generate efficient code

Related work: Prelude

Prelude: language for integration

- Links nodes (implemented in Lustre) together
  - Equational language similar to Lustre
  - Nodes are associated with a wcet
  - No computation outside of node calls

- Force clocks to be of the previously mentioned form
  - Operators to sub/over-sample ($*k$ and $/k$)

- Real-time information (duration of a period known)

- Relaxed synchronous hypothesis: execution must end before the next tick of a clock

$\leadsto$ $\neq$ Lustre Code Generation strategy (no step function)

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$\Rightarrow$ Can we do something similar, but in the Lustre formalism?

Determining clocks in an integration specification

- Two components inside a clock: period and a *phase*
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- **Case study:** Flight control application
  - 6000 nodes, 30k data communicated
  - Base clock is 5 ms
  - Nodes associated to 4 different periods (10/20/40/120 ms)

$\Rightarrow$ Fixing all clocks by hand is tedious

Contributions

1. Formalization of harmonic clocks in Lustre
    - Strict synchronous hypothesis ($\neq$ Prelude)
    - Same expressiveness than Prelude
    - Idea for efficient code generation
2. Clocks partially defined (i.e., period only provided)
    - Infer their phase at compile time
    - Provides minimal information to be deterministic
    - Easier to write multiperiodic Lustre code

Outline

1. Introduction
2. Harmonic clock
3. Partially defined clock
4. Conclusion

Rate tree

- **Rate:** set of strictly periodic clocks sharing the same period

$$\{\ 0^k(10^{n-1}) \mid 0 \leq k < n\ \}$$

- **Rate tree:** Tree of rates
  - Root: base rate (contains only the base clock)
  - Edge: represent the harmonic ratio between 2 rates
- **Example:**

$$\mathrm{r1} \xrightarrow{2} \mathrm{r2} \xrightarrow{2} \mathrm{r3} \xrightarrow{3} \mathrm{r4}$$

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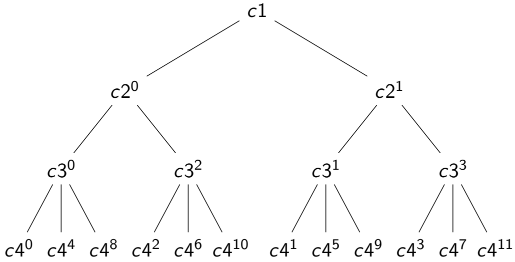
- **Local ratio:** ratio of the incoming edge
- **Global ratio:** product of the ratio of the path from the root

Clock tree



- Edge = sub-clock relation
- Path on this tree = definition of a clock
  Example: $c4^2 = (1)$ *on* (10) *on* (01) *on* $(100) = 0^2(10^{11})$
- Clock tree derived from rate tree
  - $\rightarrow$ Constructor to build the set of clocks associated to a rate

Navigating the clock tree

Three operators which changes the clock

- **when:** Sub-sampling operator

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$\Rightarrow$ Syntactic sugar: `current` (over-sampling operator)

`Var2 = current(`$c2^1$`,` $c1$`, Init, Var1);`

- **`buffer1`:** Communicate between clocks of the same rate

`Var2 = buffer1(`$c3^1$`,` $c3^3$`, Init, Var1);`

where `Var1 ::` $c3^1$, `Var2 ::` $c3^3$

$\Rightarrow$ Can be viewed as combination of when/merge

Efficient Code Generation

- Step function $\leftrightarrow$ base clock
- Using these operator allows us to compile them efficiently

- `buffer1`
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- `current`
  - One update which is repeated until the next one
  - Use a `set` for multiple `get`

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- Phase of a clock = part of a (large-grain) schedule
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- **Issue:** need to specify it in the Lustre code
  - Tedious for large applications
- **Solution:** Only specify the period for some variable.
  - Compiler find automatically the phase

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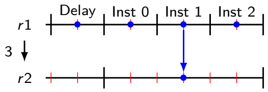
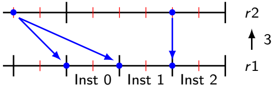
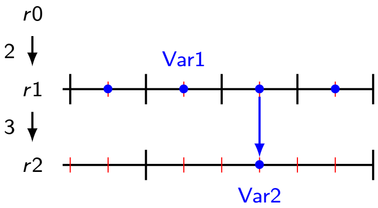
- **Issue:** non-determinism on dependences with different rates





Determinism - fast to slow rate



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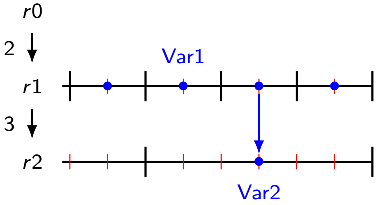
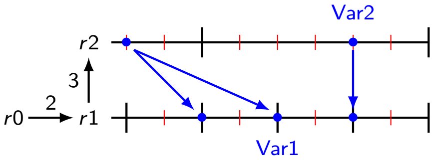


- Need to precise which value of Var1 is used
- **Idea:** New boolean variable `bwhen(r,i)`, $0 \leq i < locRatio(r)$

```
Var2 = f(Var1 when bwhen(r2,1));
```

  where `bwhen(r2,1)`:
  - Is a fresh variable
  - Has the same clock than Var1 (unknown right now)
  - bwhen(r2,1) $=$ (FTF)
- bwhen can automatically be obtained with the rate tree

Determinism - slow to fast rate



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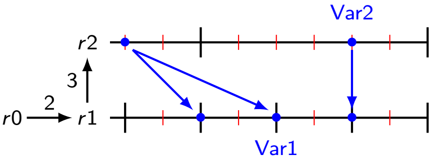

- Need to precise when the value of Var2 is available
- **Idea:** reuse the previously introduced boolean `bwhen(r,i)`

```
Var1 = f(merge bwhen(r2,2) Var2
                           (0 fby Var1));
```

where `bwhen(r2,2)::clock(Var1) = (FFT)` will be a fresh variable

Constraint extraction

We want to find the phase of all variable with incomplete information

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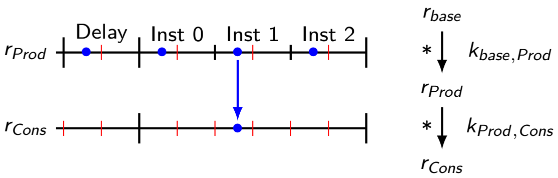
  - Can add a constraint which forces the use of the previous value before the new value is computed (allow memory reuse)

Constraint extraction (Bonus - 1)



Fast rate to slow rate - Two situations:

- Previous value is used $\Rightarrow$ No constraint
- i-th value used $\Rightarrow p_{Prod} + i \times k_{base,Prod} \leq p_{Cons}$

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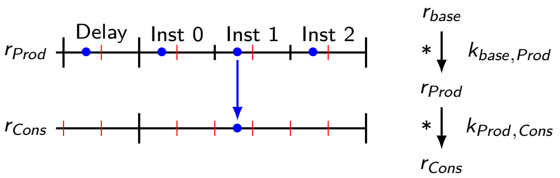

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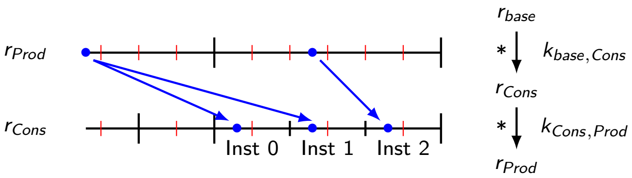
(Optional constraint) No extra memory

- Previous value is used $\Rightarrow p_{Cons} <= p_{Prod} + 0 \times k_{base,Prod}$
- i-th value used $\Rightarrow p_{Cons} <= p_{Prod} + (i+1) \times k_{base,Prod}$

Constraint extraction (Bonus - 2)



Slow rate to fast rate - Two situations:

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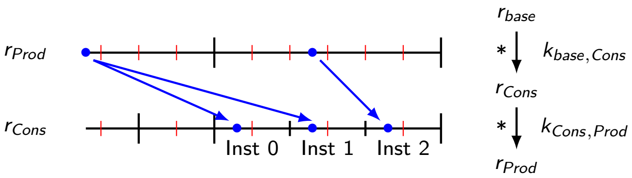

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Several possibilities (which can be combined). Mostly naive

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- WCET load balancing
  - Need to introduce a quadratic number of boolean variable (one per equation/possible phase)
  - Quadratic number of constraints added, some of them linear

  $\Rightarrow$ Costly (how much?)

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- **Last part:** reinject a solution in the Lustre program
  - Clocks are now fully defined
  - Explicit `buffer1` when needed
  - Can verify the validity of the solution

$\Rightarrow$ Ends up with a classical Lustre program

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    - How to group nodes for parallelism?
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$\approx$ Hyperperiod extension ($\rightarrow$ Prelude?)