

Céu: A low-level imperative  
reactive language

# Objective

- Support both *Esterel* and *FRP* functionality
  - both models are *synchronous* and *reactive*
- Esterel (imperative/control)
- FRP (declarative/data)

```
do
  every STEP do
    emit JUMP
  end
watching LAP
```

```
x = integral v dt
v = integral a dt
a = <ui_control>
```

# Overview

- Reactive
  - environment in control: *events*
- Concurrent
  - multiple lines of execution: *trails*
- Deterministic
  - always yields the same outcome for a given timeline
- Synchronous
  - trails synchronize at each event
- Imperative
  - sequences, loops, assignments

# Examples

`( ~Key ~> Print )*`

`( ~Step; ~>Jump )* || ~Lap`

# Execution Model

- Time: *discrete sequence of external input events*
  - sequence: only one event reacts at a time
  - discrete: a reaction executes in bounded time
- 1) Program starts in one trail from the 1<sup>st</sup> expression.
- 2) Active trails execute without interruption. (*Reaction Chain*)
- 3) Check termination.
- 4) Await next event and repeat Step 2.

# Example

$$(\sim\text{Tick} \Rightarrow v) * \mid \mid (\sim\text{End} ; v)$$

Timeline:

2  $\sim>$  Tick

3  $\sim>$  Tick

$\sim>$  End

# Temporal Analysis

- Bounded execution
  - *Loops:*  $\sim A ; (1)^*$
  - *Operators:*  $1 \rightarrow op$
- Determinism
  - $1 \Rightarrow v \mid \mid 2 \Rightarrow v$
  - $1 \mid \mid 2$
  - $(1^{\wedge} \ \&\& \ 2^{\wedge})^*$

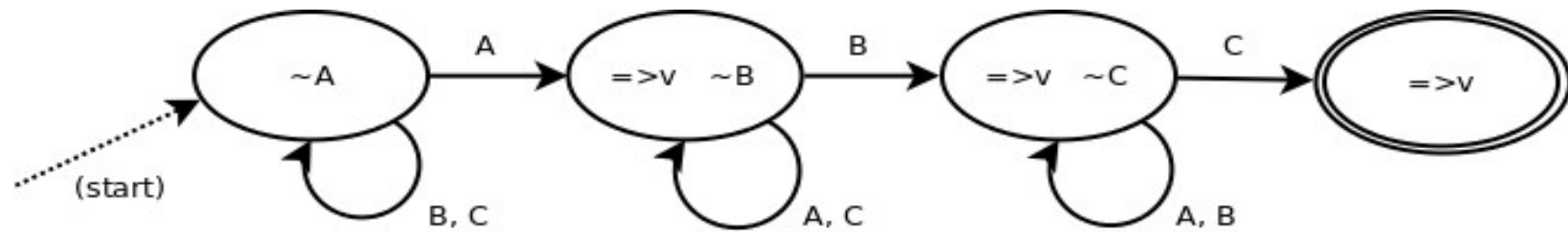
# Céu -> DFA

- DFA
  - State: what to execute and what to await
  - Transition: events
- Detects:
  - concurrent access to variables or events
  - concurrent *split/or* termination
  - concurrent loop escape
  - unreachable expressions
  - whether a program can terminate or not



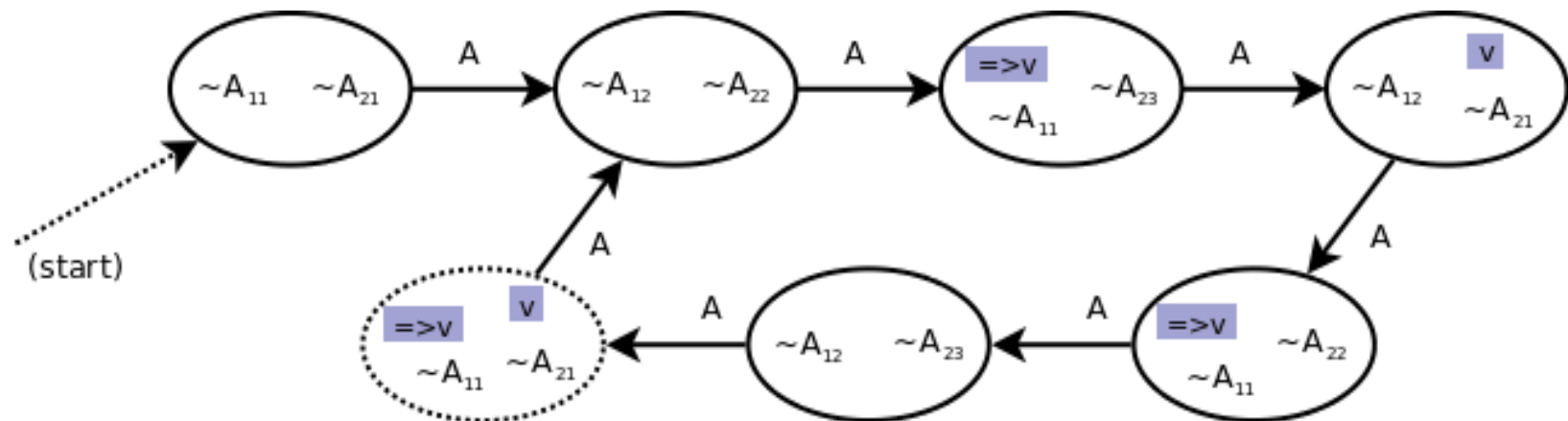
# DFA example 1

$\sim A \Rightarrow v$  ;  $\sim B \Rightarrow v$  ;  $\sim C \Rightarrow v$



# DFA example 2

$(\sim A ; \sim A ; 1 \Rightarrow v)^* \ \&\& \ (\sim A ; \sim A ; \sim A ; v)^*$



- *Basic Céu:*

- similar to Esterel (equivalent?)
- better support for variables (still deterministic)

- *Extended Céu:*

- internal events -> FRP
- "physical" time
- asynchronous blocks -> unbounded & simulation

# Internal events

- Communication mechanism among trails

`(~a ~> Print)* || (~Key ~> a)*`

- internal events  $\Leftrightarrow$  variables : *reactive variables*
- Stack based execution policy:

```
(  0=>v ; ~Start ;  
    1~>a ; v->inc=>v    -- expr.1  
&&  
    ~a~>b ; v->inc=>v    -- expr.2  
&&  
    ~b~>c ; v->inc=>v ) -- expr.3
```

# FRP

- Behaviors:  $(\text{pos2} = \text{pos1} + 20)$

$((\sim \text{pos1}, 20) \rightarrow \text{add} \sim \rightarrow \text{pos2})^*$

- Integral:  $(\text{pos} = S(v, dt))$

$((\text{pos}, (v, \sim DT) \rightarrow \text{mul}) \rightarrow \text{add} \sim \rightarrow \text{pos})^*$

- Cyclic dependency:

$(( (\sim \text{fahr}, 32) \rightarrow \text{sub}, 5) \rightarrow \text{mul}, 9) \rightarrow \text{div} \sim \rightarrow \text{celc})^*$

||

$(( (\sim \text{celc}, 32) \rightarrow \text{add}, 9) \rightarrow \text{mul}, 5) \rightarrow \text{div} \sim \rightarrow \text{fahr})^*$

# Physical Time

- Time from real world, in hours, milliseconds, etc.
- Most used input event (sampling, watchdogs, animations)
- *Timers* in conventional languages:
  - cannot ensure zero delay
  - *residual delta time* (dt)
- Time is a physical quantity:
  - comparable, addable

# Physical Time in Céu

- Syntax similar to events    `~1h30m10s500ms`
- *dt* is accessible:                    `~1s500ms => v`
- *dt* is taken into account: `~50ms ; ~50ms ; ...`
- Time is comparable:
  - `(~50ms ; ... ; ~49ms) || ~100ms`
  - `(~50ms ; ... ; ~50ms ; v) || (~100ms ; 1=>v)`
- Avoids "Collision Tunneling":
  - `((pos, (100, ~DT)->mul)->add ~> pos)*`            (wrong!)
  - `(~10ms ; pos->inc~>pos)*`                            (right!)

# Asynchronous Blocks

- Bounded execution -> no unbounded loops
- @ { ... } can have unbounded loops, but:
  - assigned variables are local
  - split blocks disallowed
  - awaiting disallowed
  - executes while no input events
- Equivalent to unique I/O events:
  - ~>Async\_XXX\_ini ; ~Async\_XXX\_end
- Subjected to *split/or* termination:
  - ~timeout || @ { ... }



# Simulation in Céu

- *Asyncns* are allowed to trigger
  - external *input* events
  - passage of time

```
(~10ms ; pos->inc~>pos)*
```

```
||
```

```
@{ ~>1s35ms ; (pos,103)->eq->assert) }
```

# Conclusion

- Céu ~ Esterel + FRP
  - kernel as complex as Esterel
  - FRP: state changes + internal events
- Internal events
  - handles cyclic dependencies
- Physical Time
  - convenient syntax, *dt* awareness, avoids tunneling
- Asynchronous blocks
  - unbounded execution + simulation
- Temporal Analysis
  - determinism / physical time

# Next Steps

- Formal Semantics
  - compare to Esterel and FRP
- Proofs
  - temporal analysis
- Expressiveness
  - type system
  - dynamic code
- Implementation
  - parser
  - parallelism

# The *basic* Céu

seq:	e1 ; e2 ; ...
and:	e1 && e2 && ...
or:	e1    e2    ...
cond:	(e1 ? e2 : e3)
loop:	(e)*
break:	e^
load:	ID
await:	~ID
assign:	e => ID
trigger:	e ~> ID
op:	e -> ID
exp:	<all above>   CONST