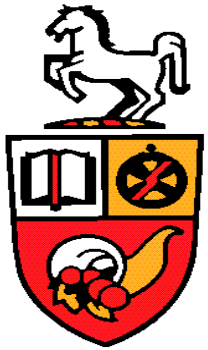
Supporting Timed CSP Operators in CSP++



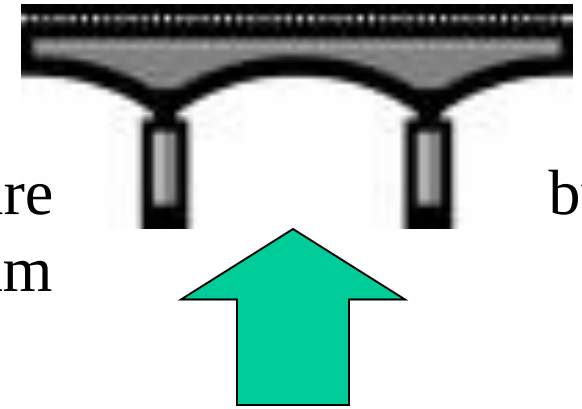
William B. Gardner & Yuriy Solovyov

Modeling & Design Automation Group
School of Computer Science
University of Guelph, Ontario, Canada

Outline

1. Overview of CSP++
2. Adding timed operators to CSP++
   - Verification and validation approaches
   - Translator, run-time framework, performance
3. Case study
4. Conclusion & future plans
5. Obtaining open source CSP++, contributing

1. Overview of Approach



CSP
formal "backbone"
models control structure
interprocess sync/comm
verification tools

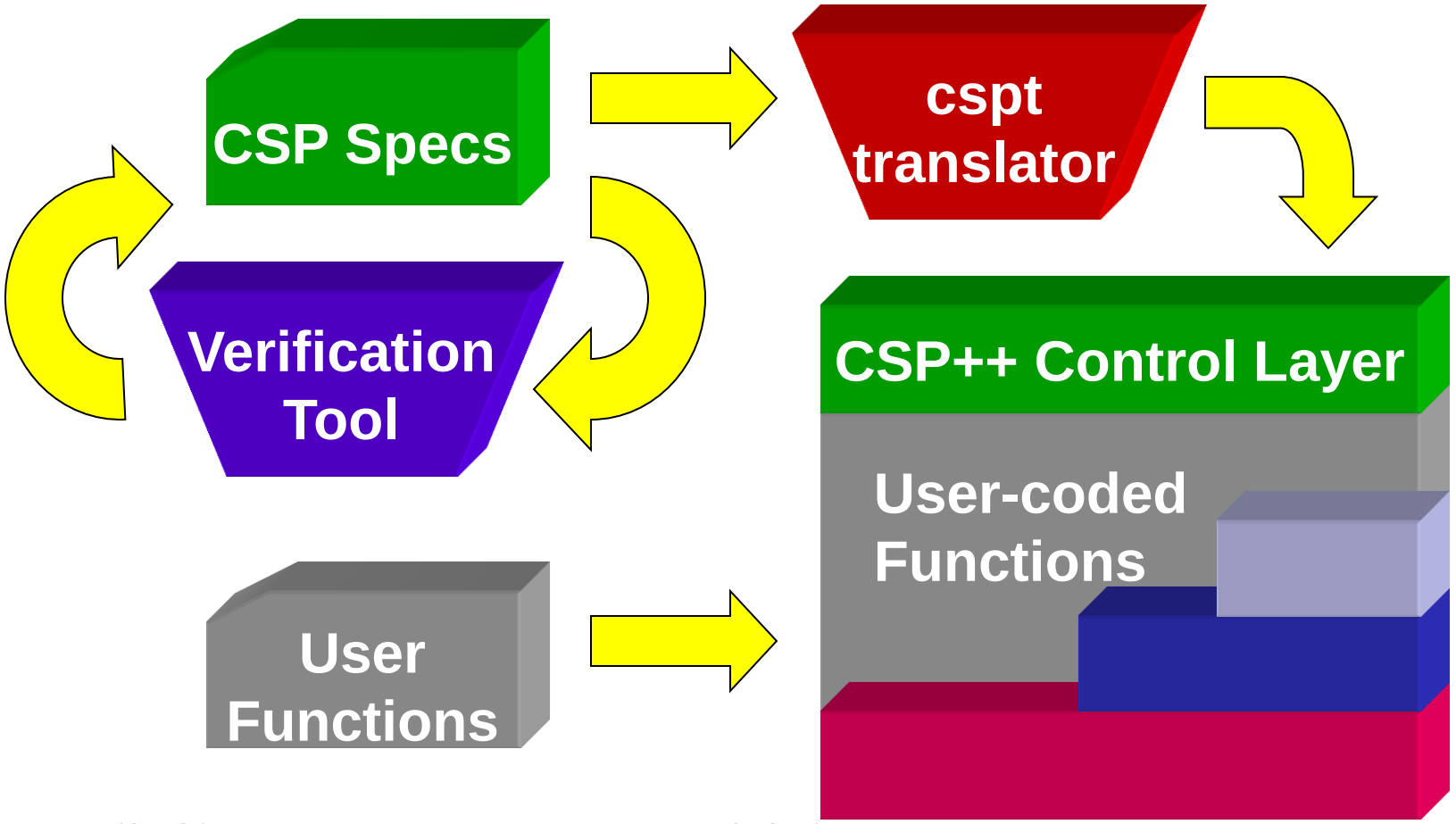
C++
plug-in modules
bulk of data processing
external I/O
restrictions (no IPC)

CSP++
implements CSP computation model
invokes plug-in modules
handles interprocess sync/comm
Bridge between CSP and popular programming language

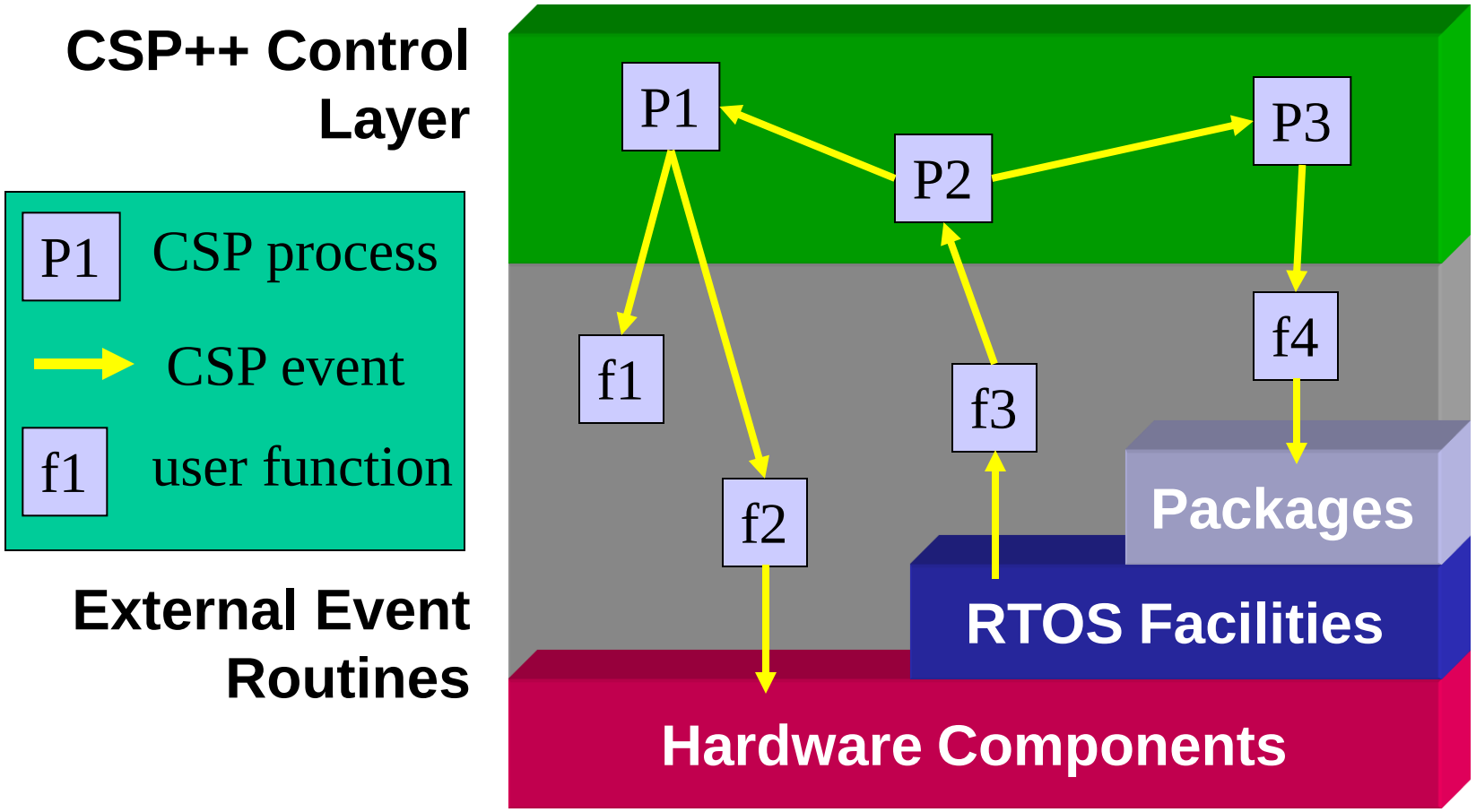
Notion of "selective formalism"

- Designer decides *how much* of system to model in CSP vs. C++
- Conceptual line between formal high-level spec and lower-level programming realization
  - move line "down" to enforce more rigorous formal modeling
  - move line "up" for reasons of efficiency or richness of language constructs
  - CSP not intended as full-featured prog. language

CSP++ Design Flow



Integration of User Code



Restrictions on User Code

- Can link to individual events, or multiple cooperating events of leaf-level process
- Cannot rely on static storage (due to multiple process instances) except as could be provided by framework *(future work)*
- Cannot "go behind back" of CSP spec to contact other processes
  - preserves convention that interprocess communication/synchronization done via CSP

Related work

- NOCC compiler translates MCSP to execute on KRoC runtime [Barnes 2006]
- Component libraries with CSP semantics
  - JCSP/CCSP/C++CSP2; CTJ/CTC++; JACK
- [Raju et al 2003] translates CSPm to CTJ, JCSP, CCSP
  - CSP++ supports more operators →

Table 1. Translation support for FDR2's CSPm

FDR2's CSPm Features	CSP-to-			CSP++
	CTJ	JCSP	CCSP	
Comments: --	X	X	X	X
Comments: {- ... -}		X	X	X
Integer data	X	X	X	X
Declarations	X	X	X	(1)
Process definitions	X	X	X	X
Recursive processes	X	X	X	X
Parameterized processes: P(2,1)				X
Prefix: ->	X	X	X	X
Chan?data, chan!data	X	X	X	X
Chan?d1.d2. .., chan!d1.d2. ...	X	X	X	X
If ... then ... else ...	X	X	X	X
External choice (alternative): []	X	X	X	X
Interface (sharing) parallel: [|{|...|}|]	X	X	X	X
Interleaving parallel: P|||Q				X
Sequential composition: P;Q				X
Event renaming: [[e<-f]]				X
Event hiding: \{e}				X

Note (1): not needed for synthesis (treated as one-line comments)

Not supported

Boolean guard: &	Linked and alphabetized parallel
Replicated operators: @	Interrupt: /\
Untimed timeout: [>	Sequences and sets

2. Adding timed operators to CSP++

- *Original motivation:* modeling of financial transactions
- Modeling of "soft" real-time systems
  - Not safety-critical, where timing constraints must be guaranteed
- Had planned to support *untimed* interrupt /\ and timeout [> — may as well add timed counterparts

Verification approaches

- For untimed portions of spec, or where timing does not affect sync with other processes, remove time constants and use FDR2 as usual
- Where timing is important, can use HORAE tool [Dong et al 2006, Nat. Univ. Singapore], minimal syntax difference from CSP++
- *New option:* convert timed operators to tock equivalent, and use FDR 2.94 feature that allows processes to sync on tock without resolving choice

Post-run trace validation

- Run program with –t option to output trace
- Python script available to format and send trace to FDR2 to check trace refinement of CSPm spec

5 new operators

- Timed prefix: `a -5-> b -2-> SKIP`
  - At least *t* time units will elapse before next event
- Timed timeout: `a->P [10> Q`
  - Give a *t* time units to start, else continue as Q
    - First event a should be subject to synchronization
- Untimed timeout: `P [> e->Q`
  - Event e will preempt P from starting

5 new operators (cont.)

- Untimed interrupt: `P /\ e->Q`
  - Event e will grab control from unfinished P
- Timed interrupt: `P /8\ Q`
  - P has *t* time units to finish, else Q grabs control
    - Not like operating system interrupt!

Notes:

- Interrupt applies to all subprocesses of P
- Set time unit by pragma or run-time option
  - msec, second, minute, hour

Timed prefix

- Implementation
  - Translator generates a call to framework function to make thread sleep for *t* time units
- Special considerations
  - In case process is in scope of interrupt operator, timed wait must be interruptible
    - GNU Pth allows this

Timeouts

- Both timeouts treated as a kind of deterministic choice: `a->P "[]" e->Q`
  - If event a succeeds (does not block), P wins and the timeout to Q does not occur
- Timed version: `a->P [10> Q`
  - Limit blocking wait for event a to *t* time units (interruptible like timed prefix blocking)

"Untimed" timeout

- Untimed version: `a->P [> Q`
  - Try a first; if not succeed, resolve choice to Q
- A valid and useful "polling" interpretation
  - Different from regular choice `a->P [] b->Q`
    - CSP++ tries alternatives from left to right anyway
    - Normally, if a and b don't succeed, keeps waiting for both, but in [> case, if a does not succeed, it loses its chance and "times out" to b->Q

Interrupts

- *Main challenge:* extricating thread of control from interrupted process so that…
  - it does not contribute any more events to the system trace following the interrupting event
  - all internal data structures are cleaned up
- *Key method:* interrupting event triggers interrupted process to throw C++ exception
  - CSP++ avoided exceptions for fear of overhead

Implementing interrupts

```
S = P /\ e->Q
```

- Translator generates code to push EnvInt object on S's environment stack
  - Acts as control centre for that interrupt
  - Nested interrupt operators work as well!
- Event e is tried first:
  - If succeeds, P never starts, S continues as Q
  - Else, spawns thread for P, and S waits for e

Interrupts (cont.)

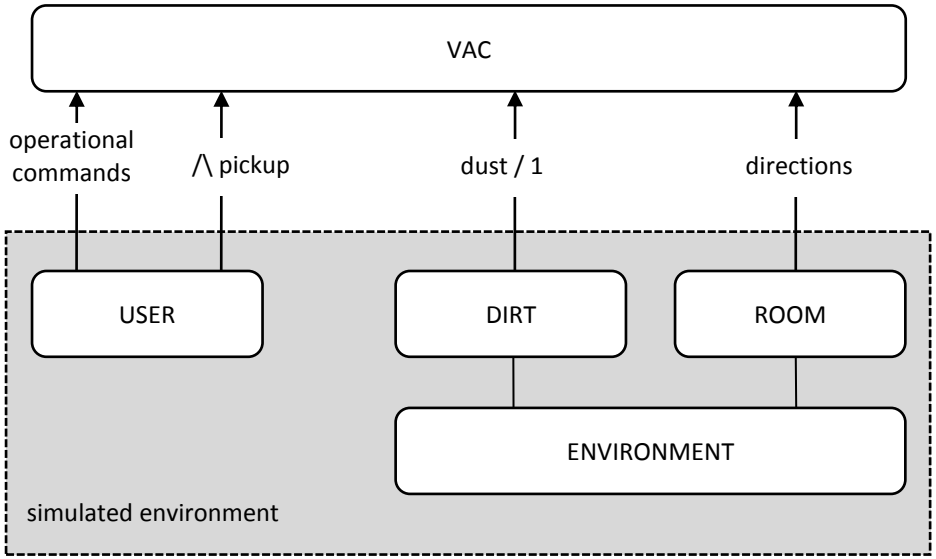
- P's events executing under scope of EnvInt environment object check its flag to see if interrupt occurred
  - If so, P throws exception, caught at "top" of thread, which cleans up and exits
- If P finishes without event e occurring, the EnvInt object is popped off and S terminates (or carries on) normally

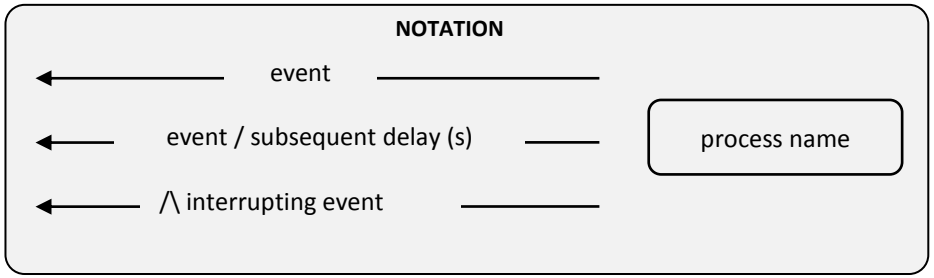
Performance impact

- *Was fear of C++ exceptions justified?*
  - "NO" (at least for g++)
- Additional execution time and memory costs were only around 1%
  - Negligible cost if no interrupts coded in spec
  - Highest cost to execute processes within scope of interrupt operator (checking flags, etc.)

3. "VAC" case study

- Robot vacuum cleaner demonstrates all new operators





VAC interrupts

```
ROBOT(1) =
   RUNNING /20\ low_battery -> SHUTOFF
```

If robot does not complete RUNNING process within 20 time units, it will cause a **low_battery** event and go into SHUTOFF.

```
RUNNING =
   WHICHOPMODE /\ pickup -> EMERGENCY_STOP
```

While running normally within WHICHOPMODE process, if a sensor detects a **pickup** event (by the human), it will immediately go into EMERGENCY_STOP.

VAC untimed timeout

```
CLEANING_MECHANISM =
   (adone -1-> SKIP) [>
   ((dust -> clean -1-> CLEANING_MECHANISM)
      [> (idle -1-> CLEANING_MECHANISM))
```

The process executes a series of checks:

- If it detects the **adone** event, it pauses one time unit and terminates.
- If not, it checks for **dust** and **clean**s it, then loops back.
- If no dust, it **idle**s for one time unit, then loops back.

VAC timed timeout

```
WHICHOPMODE =
   (manual -> REMOTE_CONTROL) [>
   ((turn_off -> ROBOT(0)) [7>
      AUTOMATIC_MODE)
```

The process checks for the **manual** mode event, and if succeeds, enters REMOTE_CONTROL.

Otherwise, it waits up to 7 time units for a **turn_off** event, which will put it into ROBOT(0). But if the timeout expires, it will default into AUTOMATIC_MODE.

4. Conclusion & Future Plans

- CSP++ makes synthesizable subset of *timed* CSPm specifications executable & extensible
  - Useful for pedagogy → CSPm simulator
  - Tool for carrying out selective formalism with user-coded C++ functions
  - Possibility of making (some) formalism more palatable & practical to the resistant

Future plans

- Work underway…
  - Making selective formalism more practical by providing mechanism for UCFs to access "process-specific storage" with managed scope
  - Garner & Roggenbach (Swansea), adding data types (sequence, set) and inline functions
- Future work includes…
  - Replicated operators (@), interruptible UCFs

5. Open source project!

- CSP++ home page
  - **www.uoguelph.ca/~gardnerw/csp++**
  - Licenses: translator GPL, run-time framework LGPL (can use to build proprietary system)
- Contributors welcome!