Taking fragile communication means into account for stream programs

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Outline

1. Context
   - Stream programming and parallel distributed systems
   - Stream programming, principles and models
   - Graph model, properties and optimization

2. The case of fragile communication links
   - Scheduling approach, case of (C)SDF
   - A new model for stream programs: TPDF

3. Conclusion

Context

Parallel distributed embedded applications cumulate several issues:

- Parallelism
- Communication between sub-parts / sub-systems
- Possibly mixed criticality
- Heterogeneity of resources

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Stream programming solves some of these issues:

- Simple programming model
- Parallelism and synchronization points are obvious both to the programmer and to the compiler
- Compilation tools can offer powerful optimization scenarios
- Most of broadly used stream programming models are deterministic and are well fit to DSP and video processing applications
- amenable to real-time constraints

Stream programming overview

The base is a directed graph (A, E, T)

- A a set of Actors
- E a set of directed edges in $A \times A$
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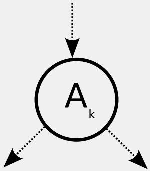
Actors

Actor A_k



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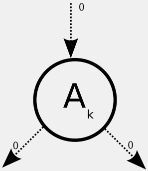

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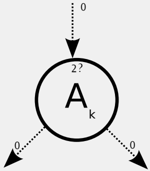

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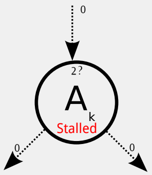

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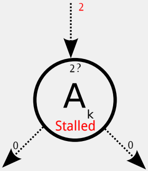

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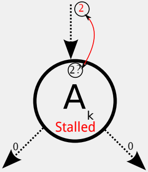

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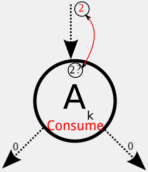

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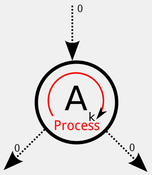

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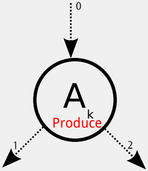

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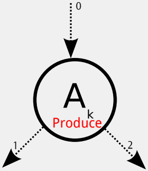

Locally deterministic

Models of computations (MoCs)

Several Models of Computation are available:

- KPN: firing rules can change freely according to the program encapsulated within the actor
- HDF: firing rules are static allowing for production and consumption of a single data token for each link
- CSDF: static firing rules are triggered according to a fixed size cycle
- SADF: commutations of firing rules according to a fixed set of scenarios
- BDF: control link allow for switching between branches
- etc.

Analizability of the MoC depends on the model. The nicest ones provide guaranties against deadlocks, livelocks and inconsistencies.

The assets of a graph representation

The graph structure allows for:

- A hierarchical definition of an application
- A set of graph transformations: coarsening, some rules of permutations or rewriting (i.e. optimization)
- A graphical representation showing in an obvious way where are the performance pitfalls
- Partitioning: good for heterogeneous computing

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SDF and CSDF models are often used when safety is important:

- Deadlock and livelock free
- Amenable to real-time constraints (RT scheduling)
- Some extensions aim to extend the expressiveness of the models

Graph optimizations

Some actors are defined to simply distribute, copy or gather data values without doing further processing

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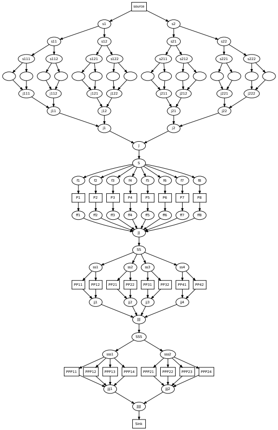

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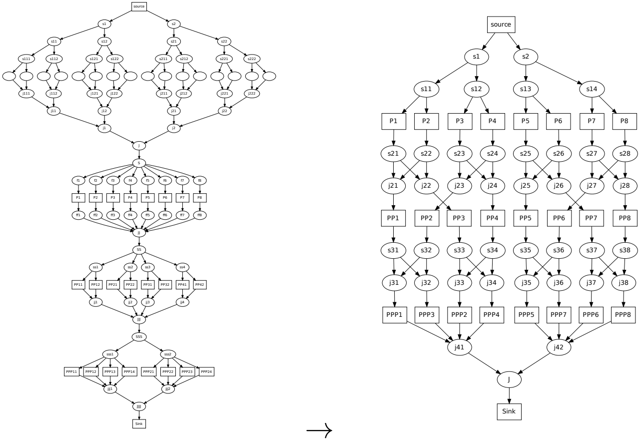

Stream programming and heterogeneous environments

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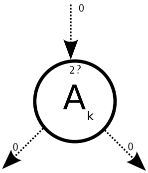
  - IoT and Home automation
  - Autonomous vehicles (e.g. traffic aware navigation)
  - Smart grids
  - Sensor networks, etc.



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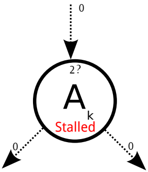

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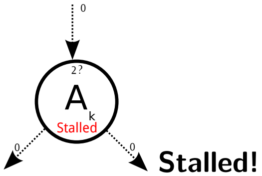
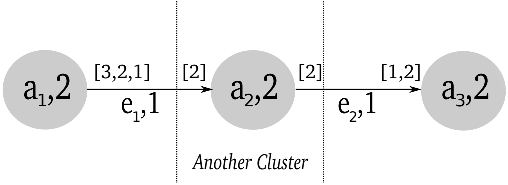


A scheduling approach for distributed systems



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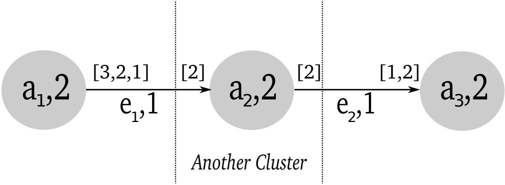

First idea: token matching with time stamping

a_1	a_2	a_3
1	1	1
2	2	2 3
3	3	4

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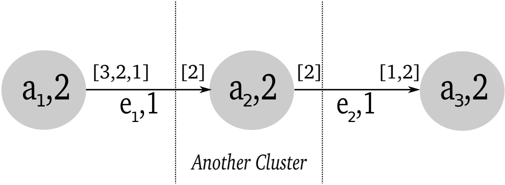

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For CSDF there exist 2 minimal repetition vectors:

$$\vec{r} = [1, 3, 2] \quad \text{and} \quad \vec{q} = [3, 3, 4]$$

These provide basis of all well-formed scheduling policies

Building RT schedule for CSDF

$$\Gamma \cdot \overrightarrow{r} = 0, \tag{1}$$

where Γ is the *topology matrix* of G.

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Period vector:

$$\lambda_i^{min} = \frac{Q}{q_i}\left\lceil \frac{\eta}{Q} \right\rceil \quad for \;\; a_i \in A, \qquad (2)$$

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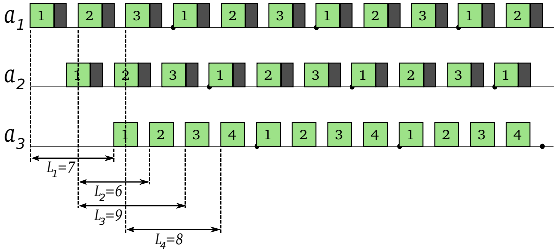

Actor Dependence Function (ADF)

$$ADF_{A \leftarrow B}(n) = \underset{\phi \in \Phi}{maxList}(|\phi \wedge A(n)| \wedge \{B\})$$

where ϕ is an ordered sequence of actor firings of a dataflow graph and Φ denotes the set of all legal schedules.

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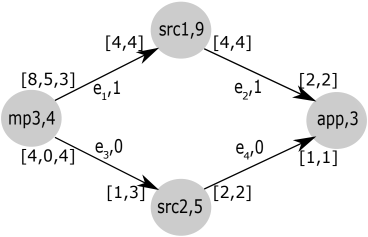
Definition of a "Late schedule": fire Actors as late as possible

Late schedule formulation

//Late Schedule: X predecessors are fired as late as possible
lateSchedule(X,n) {
$\phi = \{\}$
for $i = 1$ to n **do**
    for all input channels c_i of X **do**
        while X need more tokens on c_i in order to fire **do**
            //extend schedule ($\oplus$ denotes concatenation)
            $\phi = \phi \oplus lateSchedule(source(c_i, 1)$
        end while
    end for
    //add X to schedule
    $\phi = \phi \oplus X$
    //update number of tokens on I/O channels of X
    simulateExecution(X)
end for
return ϕ }

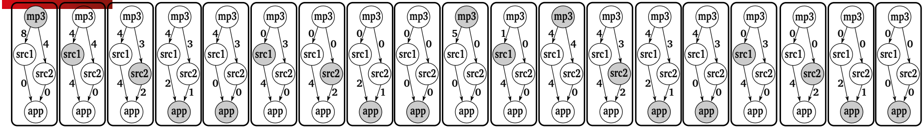
Example



And the data dependence:

mp3	src1	src2	app
1	1	1	1
			2
	2	2	3
			4
2	3		
3		3	5
			6
	4	4	7
			8

Scheduling and Actor Dependence Function (ADF)



mp3	src1	src2	app	app	src1	src2	app	app	mp3	src1	mp3	src2	app	app	src1	src2	app	app
1	1	1	1	2	2	2	3	4	2	3	3	3	5	6	4	4	7	8

Count the ordinal number of executions for each actor in Late schedule

$ADF_{mp3 \leftarrow app}(1)=\{1,2,3,4\}$ $ADF_{mp3 \leftarrow app}(2)=\{\}$ $ADF_{mp3 \leftarrow app}(3)=\{5,6,7,8\}$

$ADF_{src2 \leftarrow app}(1)=\{1,2\}$ $ADF_{src2 \leftarrow app}(2)=\{3,4\}$ $ADF_{src2 \leftarrow app}(3)=\{5,6\}$ $ADF_{src2 \leftarrow app}(4)=\{7,8\}$

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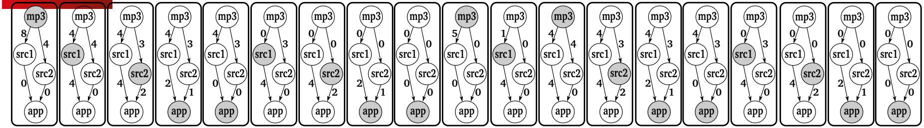

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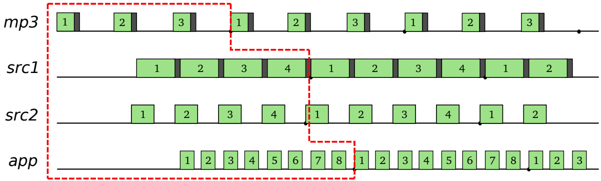
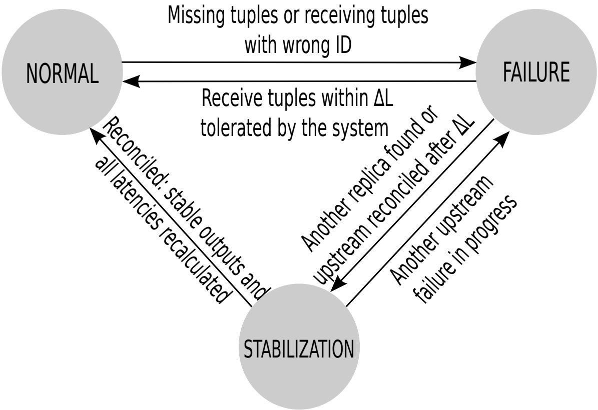


Fragile communication and fault tolerance

Model of fault tolerance within CSDF:



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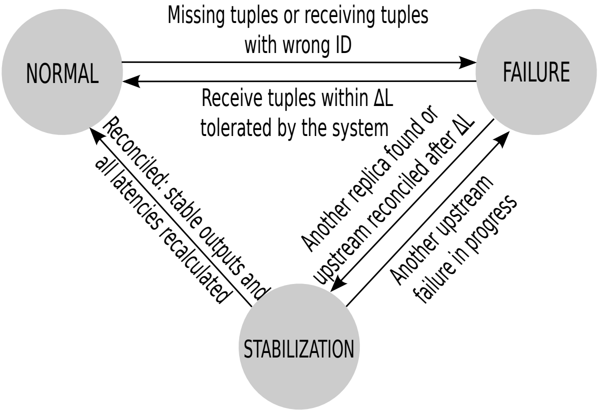
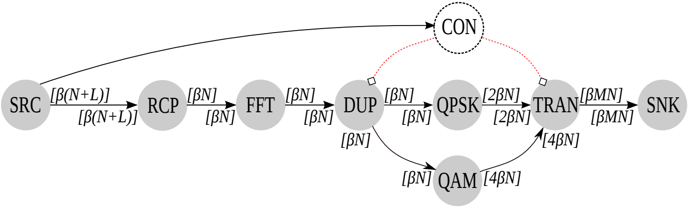


Alternatively: Modify the MoC to take uncertainties into account → TPDF

Transaction Parametrized Data-Flow

Was introduced to take into account 2 use cases:

- Dynamic rates in embedded applications: e.g. SW radio



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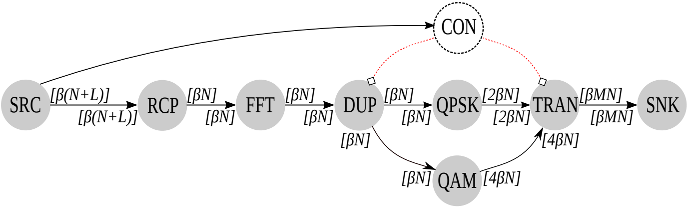
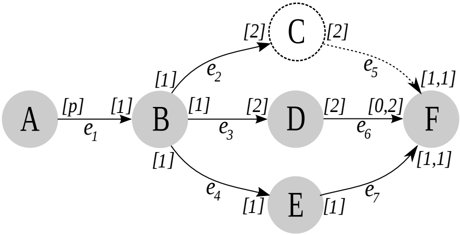


- Multiple path with fragile timing:



Properties of TPDF

TPDF is:

- globally deterministic
- RT aware
- Amenable to fault-tolerance

On going work, but well-fitted to Mixed Criticality systems

Conclusion

Stream programming is a good model for embedded and distributed applications

- Deadlock, livelock, race-condition free
- Amenable to RT constraints
- Lots of optimization and transformations on graph constructs

But requires improvements:

- For fragile communications
- For scheduling

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Future work:

- Improve the model: TPDF as one possible way
- Parameters
- Checkpoints ("Transaction") with control actors to check timing and change the execution state of the application

Thanks!

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