Static Analysis and Transformations of Dataflow Multimedia Applications

Karl-Erik Årzén, Anders Nilsson
Reglerteknik, LTH
Carl von Platen, Johan Eker
Ericsson Research

LUND INSTITUTE OF TECHNOLOGY
Lund University

ACTORS

Multicore and Manycore

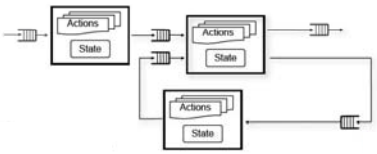
- Now: One core → dual cores and quad cores
- Eventually: 36 - 64 cores
- Tremendous computing power
- Very difficult to achieve a comparable speed-up for applications
  - In particular for communication-intense applications, e.g., media streaming
  - Due to cache effects and bus arbitration
- Dataflow programming may be the answer

ACTORS

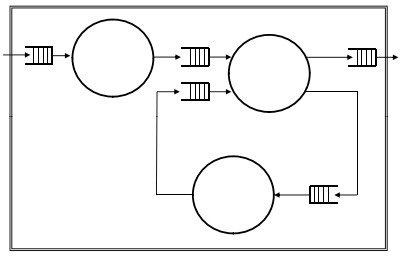
- Adaptivity and Control of Resources in Embedded Systems
- EU FP7 STREP project
  - 2008-2010
  - Coordinated by Ericsson (Johan Eker)
  - Lund University, TU Kaiserslautern, Scuola Superiore Sant'Anna di Pisa, EPFL , AKAtech , Evidence
- Dataflow programming and adaptive resource management using resource reservation techniques on Linux-based multi-core platforms

ACTORS: Dataflow Modeling

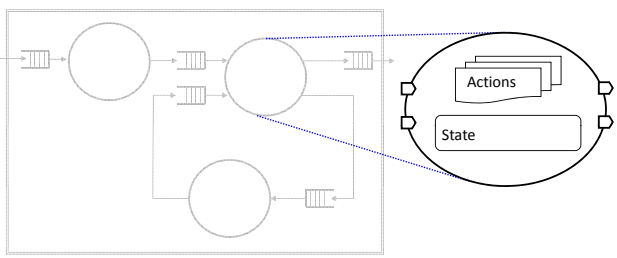
- Data flow programming with actors (Hewitt, Kahn, etc)
  - Parallelism explicit
  - Strict semantics provides foundation for analysis and model transformation
- CAL Actor Language (UC Berkeley, Xilinx) http://opendf.org
  - Part of MPEG/RVC



Actor Network

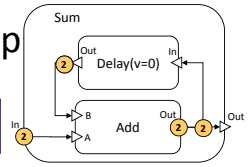


Actors & Actions



A small examp

```
actor Add() A, B ==> Out:
  action A:[a], B:[b] ==> Out:[a + b] end
end
```

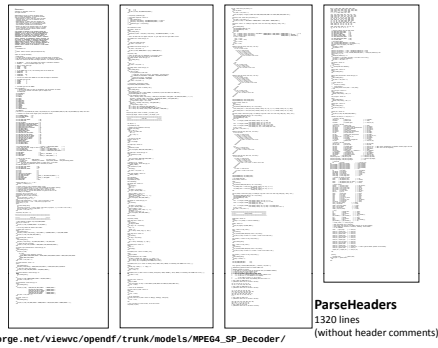



```
actor Delay(v) In ==> Out:

  A1: action ==> Out:[v] end
  A2: action In:[x] ==> Out:[x] end

  schedule fsm s0:
  ⇨s0 (A1) --> s1;
  ⇨s1 (A2) --> s1;
  end
end
```

```
network Sum() In ==> Out:

entities
  add = Add();
  delay = Delay(v=0);

structure
  In --> add.A;
  delay.Out --> add.B;

  add.Out --> delay.In;

  add.Out -- > Out;
end
```

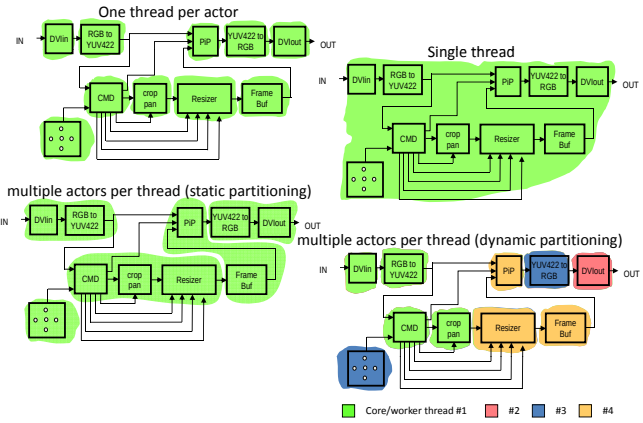
Real-life examples

Compare
23 lines
(without header comments)



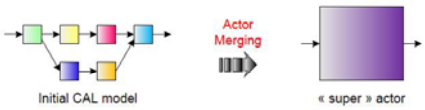
ParseHeaders
1320 lines
(without header comments)

http://opendf.svn.sourceforge.net/viewvc/opendf/trunk/models/MPEG4_SP_Decoder/



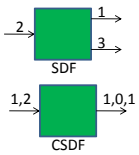
CAL Transformations

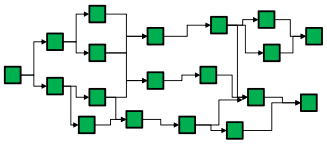
- Several possibilities to transform dataflow programs
  - Split actors to better exploit parallelism
  - Merge actors to reduce communication and synchronization overhead
  - Merge tokens ("vectorization") to reduce firing overhead
  - Split tokens to make data parallelism explicit
- This presentation: **Actor merging**



Static CAL Applications

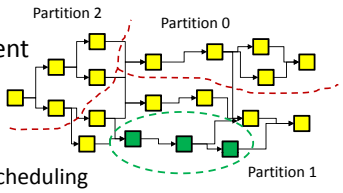
- The actors have a static I/O behavior
  - Synchronous dataflow (SDF)
  - Cyclo-static dataflow (CSDF)
- Analysis of the entire network with respect to, e.g., schedulability possible
- Quite rare





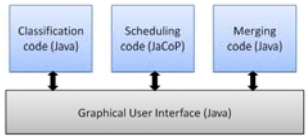
Dynamic CAL Applications

- Most actors have a data- or time-dependent behavior
- Static analysis and scheduling impossible
  - Run-time best-effort scheduling
- Some actors have a static behavior
  - The corresponding sub-network can analyzed and scheduled



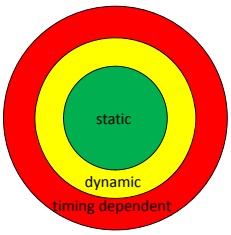
Actor Merging

- Sub-problems
  - Actor classification (Carl von Platen)
  - Finding statically schedulable sub-networks and generate the schedule (Karl-Erik Årzén)
  - Merge the actors in the sub-networks (Anders Nilsson)
- User interaction required → GUI (Karl-Erik Årzén)



Classification

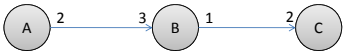
- Abstract interpretation on the XLIM level
- Classifies actors as
  - Static
    - SDF, CSDF
      - port signatures
      - which action to fire
  - Dynamic
    - Data-dependent behaviour
  - Timing dependent



Generating Schedules

- Subproblems:
  - Find the repetition vector for the network
    - The number of firings of each actor
    - ILP problem
  - Find an admissible schedule that that respects the repetition vector and optimizes some suitable criterion:
    - Minimize total buffer requirements
    - Minimize the largest buffer required
    - …….
    - NP-complete nonlinear integer problem

Finding Repetition Vector: SDF



- Incidence matrix:

$$G = \begin{bmatrix} 2 & -3 & 0 \\ 0 & 1 & -2 \end{bmatrix}$$

- Repetition vector q given by smallest integer solution to

$$Gq = 0$$

- Solution:

$$q = \begin{bmatrix} 3 & 2 & 1 \end{bmatrix}$$

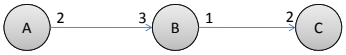
Finding a Schedule: SDF

- Lee & Messerschmitt's method for finding a PASS (Periodic Admissible Sequential Schedule)
- Algorithm:
  1. Find the repetition vector
  2. Form a list of all actors in the network
  3. For each actor in the list, schedule the actor if it is fireable, trying each node once (respect the balance equation)

$$b(n+1) = b(n) + Gv(n)$$

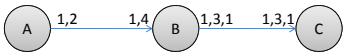
  4. Stop if each node has been scheduled the correct number of times
  5. Go to 3

Finding Schedules



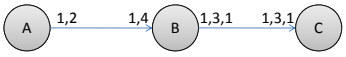
- Repetition Vector $q = \begin{bmatrix} 3 & 2 & 1 \end{bmatrix}$
- Schedules:
  - AABABC
    - Max buffer required: 4
  - AAABBC
    - Max buffer required: 6

Finding Repetition Vector: CSDF



- P_i - least common multiple of the lengths of all the token patterns of an actor
- σ_{ij} = sum of tokens in pattern
- p_{ij} - pattern length

$$T = \begin{bmatrix} P_i \frac{\sigma_{ij}}{p_{ij}} & \cdot\cdot & \cdot\cdot \\ \cdot\cdot & \cdot\cdot & \cdot\cdot \end{bmatrix} \rightarrow Tq = 0 \rightarrow P_i q =$$ Actor repetition vector

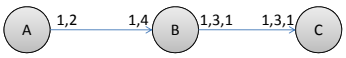


$$T = \begin{bmatrix} 3 & -15 & 0 \\ 0 & 10 & -5 \end{bmatrix} \qquad P_i = \begin{bmatrix} 2 & 6 & 3 \end{bmatrix}$$

$$q = \begin{bmatrix} 5 & 1 & 2 \end{bmatrix} \Rightarrow q_{act} = \begin{bmatrix} 10 & 6 & 6 \end{bmatrix}$$

Finding a Schedule: CSDF

- Previous approach still applicable
- Algorithm:
  1. Find the repetition vector
  2. Form a list of all actors in the network
  3. For each actor in the list, schedule the actor if it is fireable, trying each node once. Take the cyclo-static consumption rates and production rates into account in the balance equation.
  4. Stop if each node has been scheduled the correct number of times
  5. Go to 3



$$T = \begin{bmatrix} 3 & -15 & 0 \\ 0 & 10 & -5 \end{bmatrix} \qquad P_i = \begin{bmatrix} 2 & 6 & 3 \end{bmatrix}$$

$$q = \begin{bmatrix} 5 & 1 & 2 \end{bmatrix} \Rightarrow q_{act} = \begin{bmatrix} 10 & 6 & 6 \end{bmatrix}$$

A schedule that minimizes the maximum buffer: ABCAAABCBCAAABCABCAABC
Maximum buffer = 5

SDF actors a special case of CSDF → Only CSDF scheduling implementing

Mixed SDF/CSDF sub-networks handled

Implementation

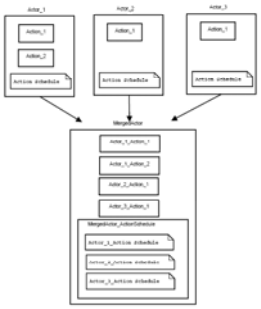
- JaCoP - Constraint Programming Solver
  - Krzysztof Kuchcinski, CS, Lund
  - Java
  - http://www.jacop.eu/
- Problem formulated in miniZinc
  - Declarative, equation-oriented language for specification of finite-domain optimization problems
  - Translated into JaCoP
- Problem formulated directly in JaCoP
  - Java code

Implementation

- NP-complete problem
  - Timeout necessary
- Optimization criteria currently supported
  - Find all schedules (within the timeout)
  - Find the schedule(s) that minimizes the total internal buffer requirements
  - Find the schedule(s) that minimizes the size of the largest internal buffer

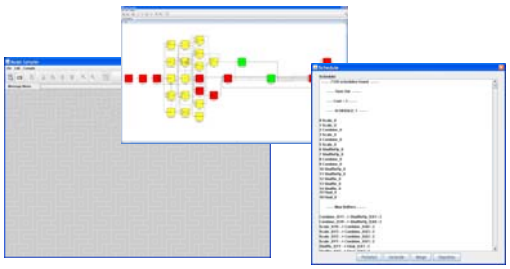
Actor Merging

- On the XLIM/XDF level
- Steps:
  - Merge actions
  - Name mangling
  - Replacement of internal FIFO buffers with state variables (ring buffers or scalars)
  - Merge action schedules



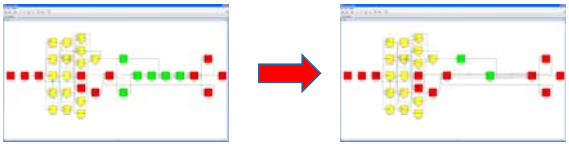
Graphical User Interface

- Java Swing
  - JGo Graphical Library



Demo

Results



- MPEG 4 Simple Profile Video Decoder
- Static subnetwork involving 5 actors
  - 1-dimensional inverse discrete cosine transform (idct1d)
- Merging gives an 18% speedup measured in terms of frames per second
- The speedup for the idct1d network in isolation is 300%

Summary

- Dataflow programming natural for media streaming applications on multicore platforms
- Static dataflow applications allows extensive off-line analysis and optimization
- A model compiler form actor merging has been developed within the ACTORS project
- 20-300% speedup depending on application

Questions?