Generalized Extraction of Real-Time Parameters for Homogeneous Synchronous Dataflow Graphs

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Overview

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Introduction

- Many multi-core systems have both streaming applications and traditional real-time applications.
- The dataflow computational model is suitable for streaming applications because:
  1. it enables the use of multi-core systems (**parallelization model**).
  2. it is a **natural paradigm** for representing them.
- A dataflow model is specified by a directed graph, where the nodes are considered as *actors* and the edges between the nodes as *channels* of data.

Background

Homogeneous Synchronous Dataflow (HSDF)

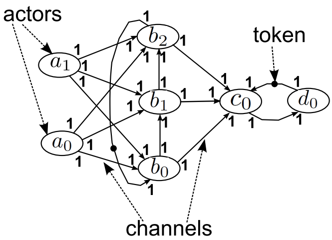
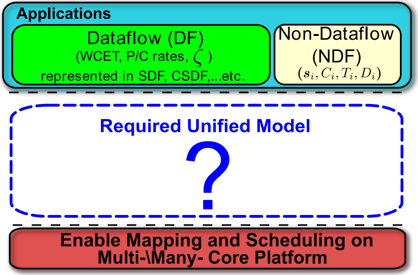


Figure: An example HSDF graph.

- Is a special case of dataflow graphs in which all rates associated with actor ports are equal to 1.
- When each actor is fired once, the distribution of tokens on all channels return to their initial state (*graph iteration*).
- Other models can be converted to an equivalent HSDF using a conversion algorithm.

Problem

To enable real-time scheduling techniques on such mixed systems, a *unified model* is required to represent both types of applications running on the system.



Problem to be addressed:

How to *Extract Timing Parameters* of real-time streaming applications modeled as HSDF Directed Cyclic Graphs (DCG)?

Existing work is restricted to dataflow applications represented as acyclic applications.

Contribution

We propose an algorithm for extracting timing parameters (s_i, C_i, T_i, D_i) of HSDF actors, where:

- $\boldsymbol{s_i}$ offset (starting time).
- $\boldsymbol{C_i}$ Worst Case Execution Time (WCET) (Given by the application).
- $\boldsymbol{T_i}$ period.
- $\boldsymbol{D_i}$ relative deadline.

Enables applying traditional real-time schedulers and analysis techniques on HSDF.

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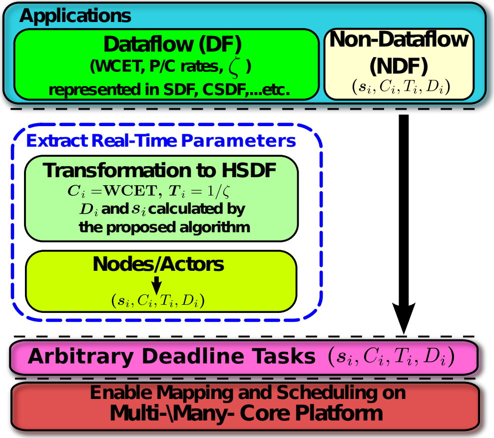
System Model



Algorithm

The proposed algorithm extracts the timing parameters (s_i, C_i, T_i, D_i) of dataflow applications with timing constraints at design time.

It consists of two main phases:

1. Finding all the possible paths in the applications graph.
2. Extracting the timing parameters of individual actors in the graph using the output information of the previous phase.

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Algorithm
Definitions

Path:

A route between two actors v_x and v_y with a latency constraint D_{xy}.

Path Sensitivity γ:

Criticality of a path with respect to *path density*. The path density is the tightness of the latency constraint D_{xy} for a path P compared to its execution time.

$$\gamma = \sum_{\forall v_j \in P} \frac{C_j}{D_{xy}}$$

Algorithm
Methods

We consider two well-known methods for pipelines (Paths):

1) The NORM method

divide the end-to-end deadline D_{xy} of a pipeline proportionally to the computation time of its tasks :

$$D_i = \frac{C_i}{\sum_{\forall v_j \in P} C_j} \cdot D_{xy}$$

2) The PURE method

distribution of the laxity $\varepsilon = D_{xy} - \sum_{\forall v_j \in P} C_j$, equally among all tasks of the pipeline, such that each task have equal slack $\delta = \frac{\varepsilon}{|V_p|}$:

$$D_i = C_i + \delta$$

Algorithm
Methods

Deriving cycle latency constraints:

HSDF applications can have several cycles. Each cycle requires a latency constraint D_{xy}^{cycle} that satisfies the throughput requirement ζ_i of the application:

- A quick choice for $D_{xy}^{cycle} = T_i = \frac{1}{\zeta_i}$.
- A better choice of D_{xy}^{cycle} considers the number of tokens involved in this cycle d_{cycle}, **to relax** D_{xy}^{cycle} and **enable capturing overlapping iterations**.

$$D_{xy}^{cycle} = \frac{d_{cycle}}{\zeta_i}$$

Refer to Section IV.B in our paper for more details.

Algorithm
Methods

Deriving end-to-end latency constraint:

In case of an HSDF application without a specified end-to-end latency constraint D_{xy}, is defined as:

$$D_{xy} = \max\{\underbrace{T_i}_{\text{period}}, \beta \cdot \underbrace{\sum_{\forall v_i \in CP} C_i}_{\text{exec. time of CP}}\}$$

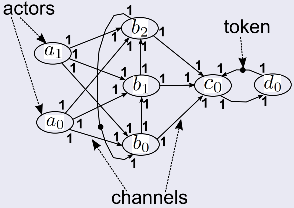
where β is a constant that ranges $[1, \infty)$.

$$\beta = \frac{1}{\max_{\forall cycle \in G}\{\gamma_{cycle}\}}$$

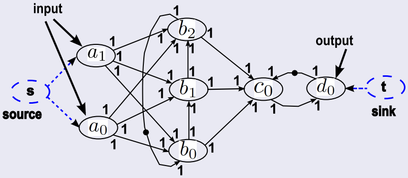
Refer to Section IV.B in our paper for more details.

First phase: Finding all possible paths

1) Creation of source and sink actors:



(a) An example HSDF graph.



(b) Adding source s and sink t.

- Unifies all the paths that traverse the graph from the input to the output of the graph have a uniform form that starts with s and end with t.
- Allows to deal with multiple input/output graphs.

First phase: Finding all possible paths

2) Path enumeration:

Partial Path :

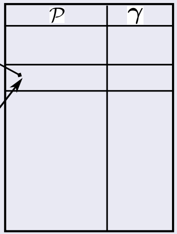
$$P_i = \langle v_x, \ldots, v_j \rangle$$

Extend Partial Path using

$$Succ(v_j) = (v_{j_1}, v_{j_2}, v_{j_3}, \ldots, v_{j_l})$$

Resulting Paths :

$$\left.\begin{array}{lcl} P_{i_1} & = & \langle v_x, \ldots, v_j, v_{j_1} \rangle \\ P_{i_2} & = & \langle v_x, \ldots, v_j, v_{j_2} \rangle \\ & \vdots & \\ P_{i_l} & = & \langle v_x, \ldots, v_j, v_{j_l} \rangle \end{array}\right\}$$



Finds all timed-constrained paths and orders them (*descendingly*) according to sensitivity γ.

Second phase: Extracting timing parameters

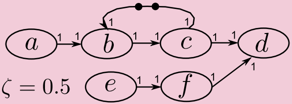
Algorithm

The second phase repeats for each application. It do the following:

1. Picks a time-constrained path P_i in order of sensitivity.
2. Each selected path P_i is assigned deadlines D_j and offsets s_j.

Example

HSDF graph example:



$\zeta = 0.5$

$C_a = C_b = C_c = C_d = C_e = C_f = 1$

$D_{ed} = 3 \quad D_{ad} = ?$

Sol: Algorithm First Phase:

We have three paths:

$P_1 = \langle e, f, d \rangle,\ D^1_{ed} = 3,\ \gamma_1 = 1$

$P_2 = \langle b, c \rangle,\ D^2_{bc} = \ ?$

$P_3 = \langle a, b, c, d \rangle,\ D^3_{ad} = \ ?$

Sol: Deriving Latency constraints:

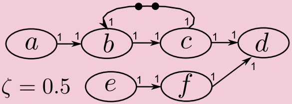
$D^2_{bc} = \frac{d_{cycle}}{\zeta} = \frac{2}{0.5} = 4,\ \gamma_2 = 0.5$

$D^3_{ad} = \max\{T_i, \beta \cdot \sum_{\forall v_i \in P_3} C_i\} = \max\{2, \frac{1}{\gamma_2} \cdot 4\} = 8,\ \gamma_3 = 0.5$

Therefore, $\mathcal{P} = \{\langle P_1, \gamma_1 \rangle, \langle P_2, \gamma_2 \rangle\ \langle P_3, \gamma_3 \rangle\} =$
$\{\langle (e, f, d), 1 \rangle, \langle (b, c), 0.5 \rangle, \langle (a, b, c, d), 0.5 \rangle\}$

Example

HSDF graph example:



$\zeta = 0.5$

$C_a = C_b = C_c = C_d = C_e = C_f = 1$

$D_{ed} = 3 \quad D_{ad} = 8$

Sol: Algorithm Second Phase:

Individual deadline calculation:

P_1: $D_e = 1, D_f = 1, D_d = 1$

P_2: $D_b = 2, D_c = 2$

P_3: $D_a = 3$

Sol: Algorithm Second Phase:

Offset assignment:

$\hat{\mathcal{P}} = \{\langle P_3, D_{ad}^3\rangle, \langle P_1, D_{ed}^1\rangle\}$

P_3: $s_a = 0, s_b = 3, s_c = 5, s_d = 7$

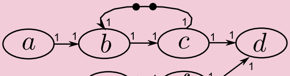
P_1: $s_e = 5, s_f = 6$

Example

Therefore:

$\{a, b, c, d, e, f\} =$
$\{(0, 1, 2, 3), (3, 1, 2, 2), (5, 1, 2, 2), (7, 1, 2, 1), (5, 1, 2, 1), (6, 1, 2, 1)\}$

HSDF graph example:

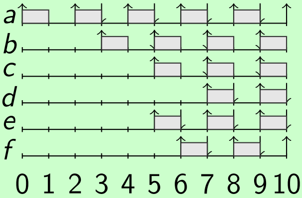


$\zeta = 0.5$

$C_a = C_b = C_c = C_d = C_e = C_f = 1$

$D_{ed} = 3 \quad D_{ad} = 8$

HSDF timing diagram



Formal Validation

Through formal proofs (*refer to Section V in the paper*), we assure that the assigned timing parameters by **our proposed algorithm guarantees satisfying application timing constraint** using any known real-time scheduling algorithm.

Conclusion

- The main contribution is that the HSDF graphs can be cyclic or acyclic and the graph actors are modelled as arbitrary-deadline tasks.
- We formally proved that the assigned timing parameters satisfies the timing constraints of the application.
- It enables applying traditional real-time analysis techniques on dataflow graphs follows from representing as tasks.
- A method to assign individual deadlines and offsets for real-time dataflow actors and support for two deadline assignment techniques (NORM/PURE) that are widely used in the literature.

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Questions ?

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