Dynamic Load Balancing in Parallelization of Equation-based Models

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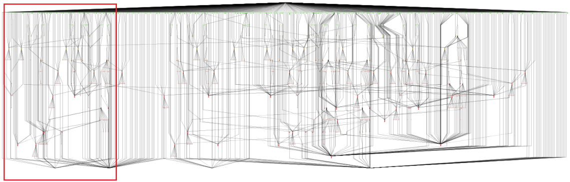
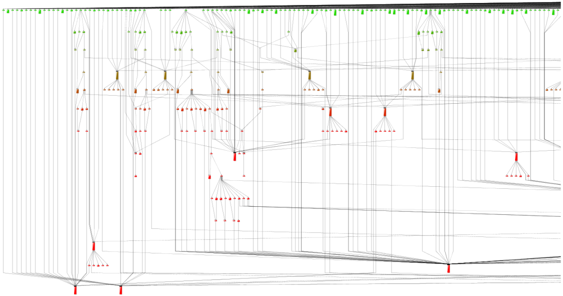
Overview

- Introduction
- Extracting Parallelism
- Task System Library
- Performance
- Future work

FourBitBinaryAdder: Dependency Task Graph





Original

- 1122 tasks
- 1360 edges

Automatic Parallelization

Improving the compiler

- Design and implementation of new automatic parallelization support for the OpenModelica compiler.
- Design and implementation of customizable task system handling library.
- Multiple clustering and scheduling options.
- Targeting shared-memory multi-core architectures.

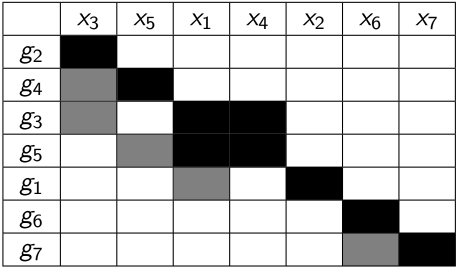
Dependency Analysis

$$
\begin{aligned}
f_1(x_1, x_2, t) &= 0\\
f_2(x_3, t) &= 0\\
f_3(x_1, x_3, x_4, t) &= 0\\
f_4(x_3, x_5, t) &= 0\\
f_5(x_1, x_4, x_5, t) &= 0\\
f_6(x_6, t) &= 0\\
f_7(x_6, x_7, t) &= 0
\end{aligned}
$$

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
f_1							
f_2							
f_3							
f_4							
f_5							
f_6							
f_7							

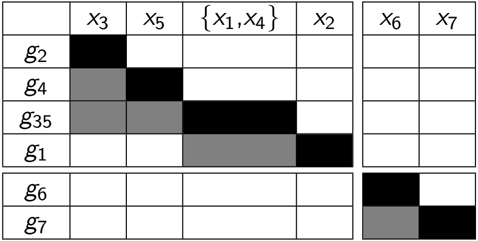
Dependency Analysis

$$
\begin{aligned}
x_3 &:= g_2(t) \\
x_5 &:= g_4(x_3, t) \\
g_3(x_1, x_3, x_4, t) &= 0 \\
g_5(x_1, x_4, x_5, t) &= 0 \\
x_2 &:= g_1(x_1, t) \\
x_6 &:= g_6(t) \\
x_7 &:= g_7(x_6, t)
\end{aligned}
$$



Strongly Connected Components

$$
\begin{aligned}
x_3 &:= g_2(t)\\
x_5 &:= g_4(x_3, t)\\
\{x_1, x_4\} &:= g_{35}(x_3, x_5, t)\\
x_2 &:= g_1(x_1, t)\\
x_6 &:= g_6(t)\\
x_7 &:= g_7(x_6, t)
\end{aligned}
$$



TLM and Decoupled Systems

Decoupled Systems

Systems $\{g_6, g_7\}$ and $\{g_2, g_4, g_{35}, g_1\}$ are not connected and can potentially run in parallel.

Transmission Line Modeling (TLM)

- Introduces *delays* to the system.
- Better decoupling by eliminating some dependencies in each time step.

Coarse Grained Parallelization

- Find all decoupled systems.
- Balance these systems.
- Evaluate them simultaneously.

TLM and Decoupled Systems

Problems with the approach

- Most models are heavily connected, i.e. limited decoupling.
- Improving decoupling with TLM requires modification to existing models.

Problems with the implementation

- Implemented as part of the normal code-generation runtime system.
- Complicates development process.

New approach

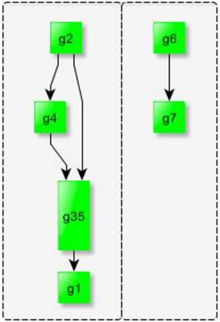
- Task graph based representation of whole system.
- Library based implementation.

From Equation Systems to Task Graphs

Directed Acyclic Graphs

$$G = (\vec{V}, \vec{E}, c)$$

	x_3	x_5	$\{x_1, x_4\}$	x_2	x_6	x_7
g_2						
g_4						
g_{35}						
g_1						
g_6						
g_7						



The Task Systems Library

What?

- Generic C++ template task system library.
  - Tasks
  - Clusters
  - Clustering algorithms
  - Scheduling algorithms
  - Profiling and execution

Dependecies

- Boost
- Intel Threading Building Blocks (TBB).

Tasks and Clusters

Tasks

- Abstract task representation that can be customized.
- Define dependency and execution rules.

Clusters

- Every vertex is a cluster.
- Originaly each cluster contains one task.
- Tasks in a single cluster are executed sequentially and in order.

Clustering Algorithms

Cost Oblivious

- Merge Single Parent (MSP)
- Merge Level Parents (MLP).

Cost Based

- Merge Children Recursive (MCR)
- Merge Level for Cost (MLC)

Profiling and Cost Estimation

Static Cost Estimation

- User provided cost values.
- Suitable for handling tasks that are executed only once.
- For simulation environments
  - Can be estimated by traversing abstract syntax trees or internal representation.

Limitations

- Not accurate.
- Some tasks are not easy to estimate, e.g. function calls, loops...
- Costs vary on different architectures.

Profiling and Cost Estimation

Dynamic Cost Estimation

- Execute once and record.
- Suitable for simulation environments.
  - Simulations execute systems repeatedly.

Current implementation

- First time step of simulation used for profiling.
- Clustering, Scheduling and subsequent evaluations use this profiling information.
- Should be done periodically.

Schedulers

Schedulers

- Collection of clustering algorithms.
- Profiling.
- Executors and synchronizations.

Available Schedulers

- Level Scheduler.
- TBB Flow Graph Based Scheduler.

Level Scheduler

Clustering

- Merge Children Recursive.
- Merge Level for Cost.

Executor

- StepSync
  - Execute all tasks in the same level.
  - Synchronize.

Level Scheduler Class

```
template<typename TaskType>
  struct LevelScheduler :
  StepSync < TaskType
           ,MCR
           ,MLC
          > {};
```

TBB Flow Graph Based Scheduler

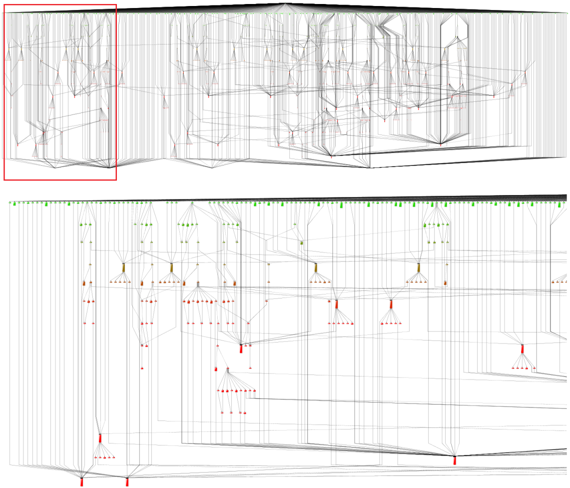
Wrapper for TBB flow_graph

- Profile the system.
- Perform Clustering.
- Construct flow graph and execute.

Why not directly create flow graph

- Clustering improves performance by reducing overhead.
- Consistency in external interface.

FourBitBinaryAdder: Dependency Task Graph Before Clustering



Original

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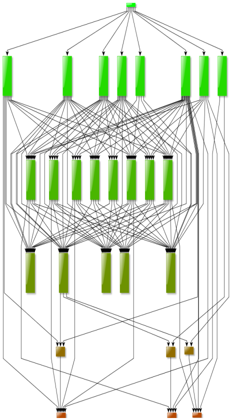
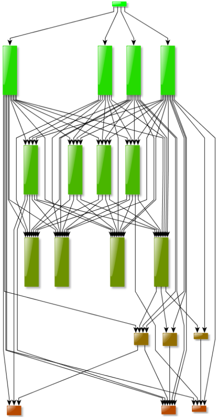
FourBitBinaryAdder: Dependency Graph after Clustering for Level Scheduler



8-way



4-way

After Merge Children Recursive

- 569 tasks
- 620 edges

After Merge Level for Cost: 8

- 27 tasks
- 121 edges

After Merge Level for Cost: 4

- 18 tasks
- 72 edges

Performance Measurements

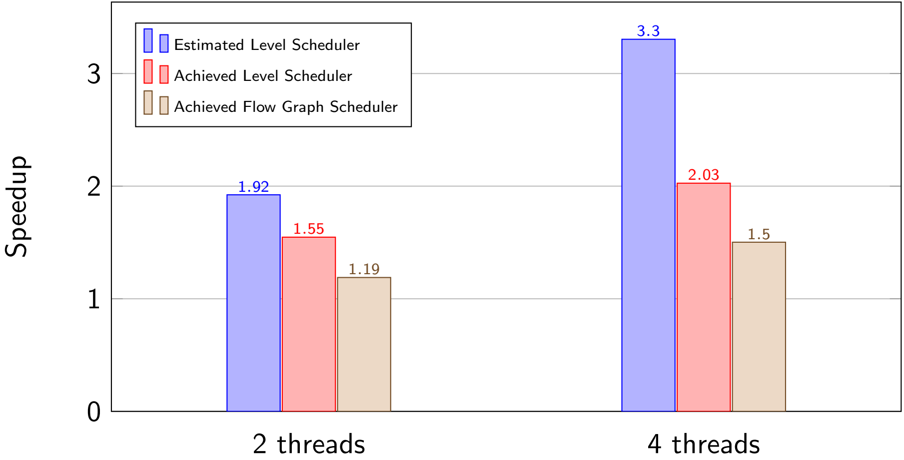
Measurement Setup

- 64-bit Intel(R) Xeon(R) W3565 CPU with 4 cores at 3.2 GHz.
- Simulation 0 to 1 second.
- Default OpenModelica Solver (DASSL)
- Only the ODE system is parallelized for each model.

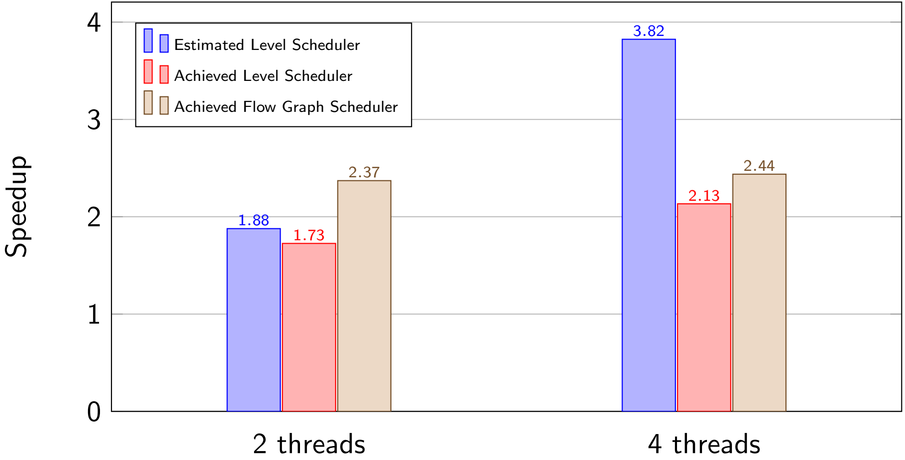
Estimated Level Scheduler Speedup

Ratio of the sequential cost to the ideal parallel cost.

CauerLowPassSC (Electrical Analog)



BranchingDynamicPipes (Fluid)



Future work

- More clustering and scheduling algorithms.
- Better adaptive rescheduling with continuous dynamic scheduling.
- Extensive testing and comparison.

Thank You!