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University of Paderborn
Design of Parallel Systems
Prof. Dr. rer. nat. Franz-J. Rammig

Temporale Partitionierung and Temporale Platzierung in Reconfigurierbarer Rechnersysteme

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Pr. Dr. rer. Nat. Franz J. Rammig
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Agenda

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- Goal
- Temporal partitioning and Temporal placement
- Solution approaches
- Tool Integration
- Previous work and New investigation
- Cooperation
- Conclusion

Goal

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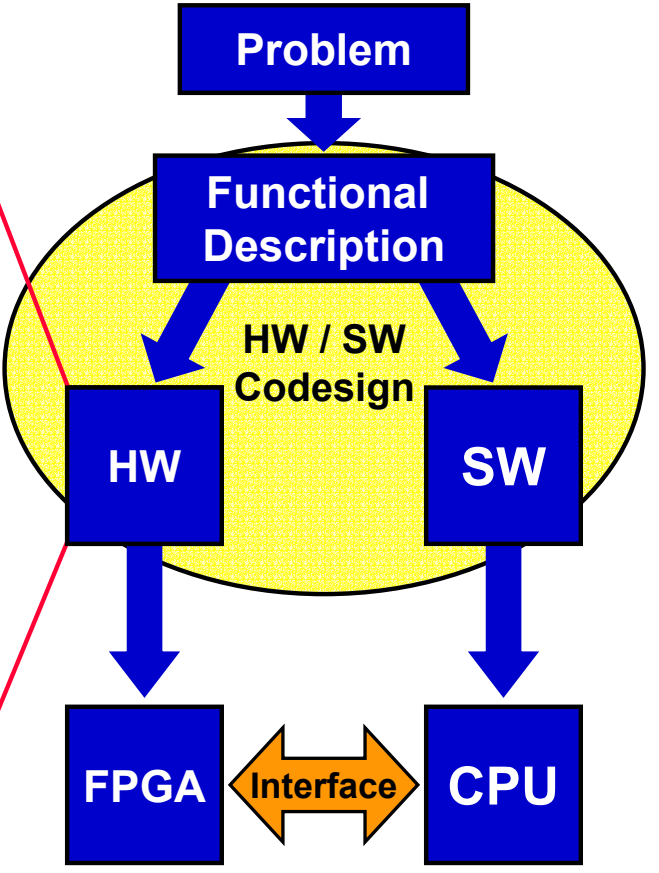
- Complex algorithms in FPGAs
- Partitioning and scheduling
  - Temporal *partitioning*
    fully reconfigurable FPGAs
  - Temporal *placement*
    partially reconfigurable FPGAs
- Development of
  - A framework for
    - Temporal Partitioning
    - Temporal Placement
  - Application on real-live problems



Temporal Partitioning (TPart)
Problem Definition

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- **Problem**
  - Function or algorithm as Control Dataflow Graph (CDFG)
  - Set of n FPGAs
- **Solution**
  - Partitioning of the CDFG into nodes or configurations (bit-streams) with respect to the FPGAs size and pins constraints.
  - Scheduling of the configurations on the FPGAs
- **Optimization goal**
  - Minimization of the overall data exchange across configurations
  - Minimization of the overall computation time
  - Maximization of the resource utilization (area, power, etc…)

Temporal Placement (TPlace)
Problem Definition

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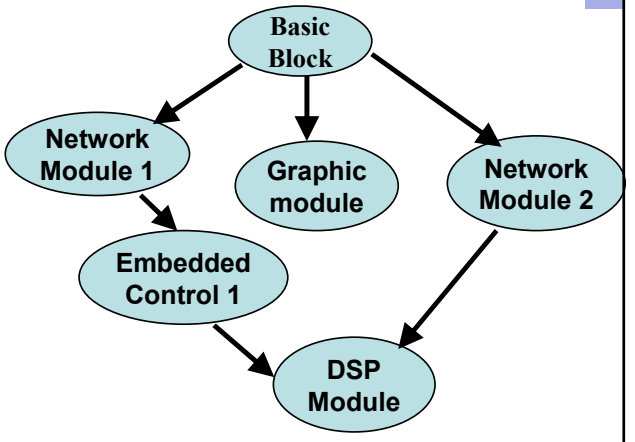
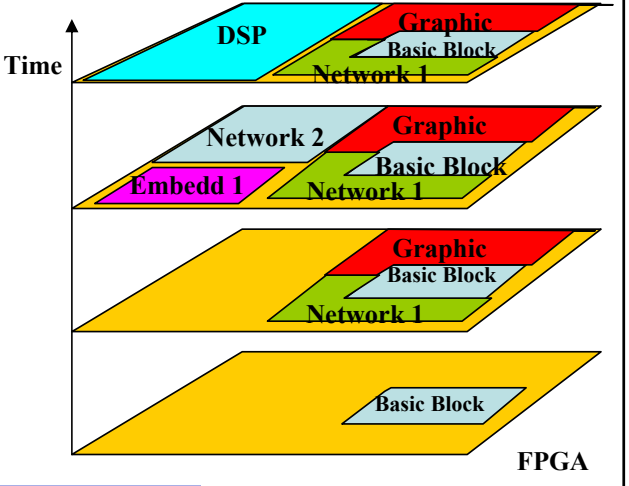
- **Problem**
  - Function or algorithm as Control Dataflow Graph (CDFG)
  - Set of n FPGAs
- **Solution**
  - Scheduling of the modules onto the FPGA for computation
- **Optimization goal**
  - Minimization of data exchange
  - Minimization of run-time
  - Minimization of resource utilization





Performance Measurement
Quality of Partitioning

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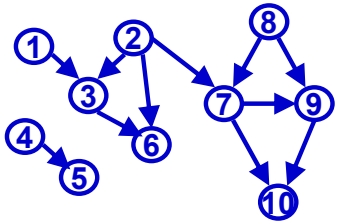
- Provide a mean to measure how good an algorithm performs (ex: The Quality)
- Connectivity of a graph G = (V, E)

$$con(G) = \frac{\#ex.Edges}{\#poss.Edges} = \frac{|E|}{\frac{1}{2}\left(|V|^2 - |V|\right)}$$

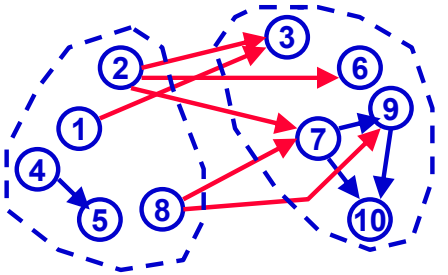
- Quality of Partitioning P = { P1, …, Pn }
  - Average connectivity over P

$$qual(P) = \frac{1}{n} \cdot \sum_{i=1}^{n} con(P_i)$$

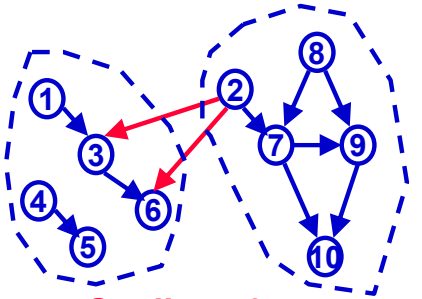
  - High quality ⇔ Algorithm performs well
  - Low quality ⇔ Algorithm performs poor



Connectivity = 0.24



Quality = 0.25



Quality = 0.45

Performance Measurement
Amount of Wasted resource

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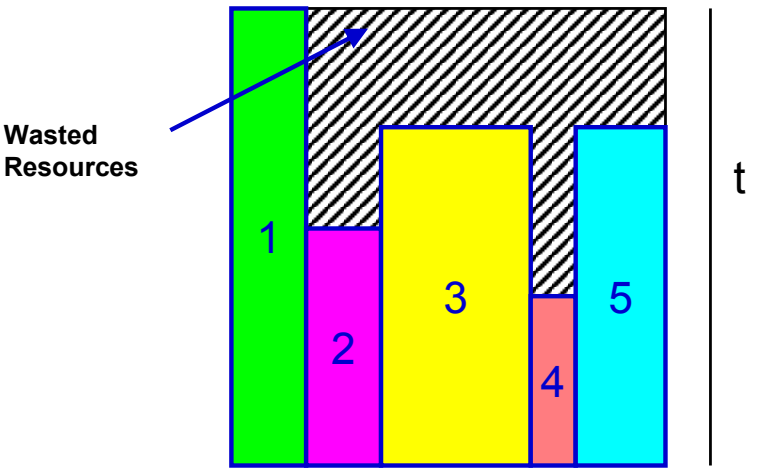
- **Amount of wasted resources of a set of components**

$$wr(C) = \sum_{v_i \in C} (t(C) - t_i) * a_i$$



Temporal Partitioning
Solution Approach

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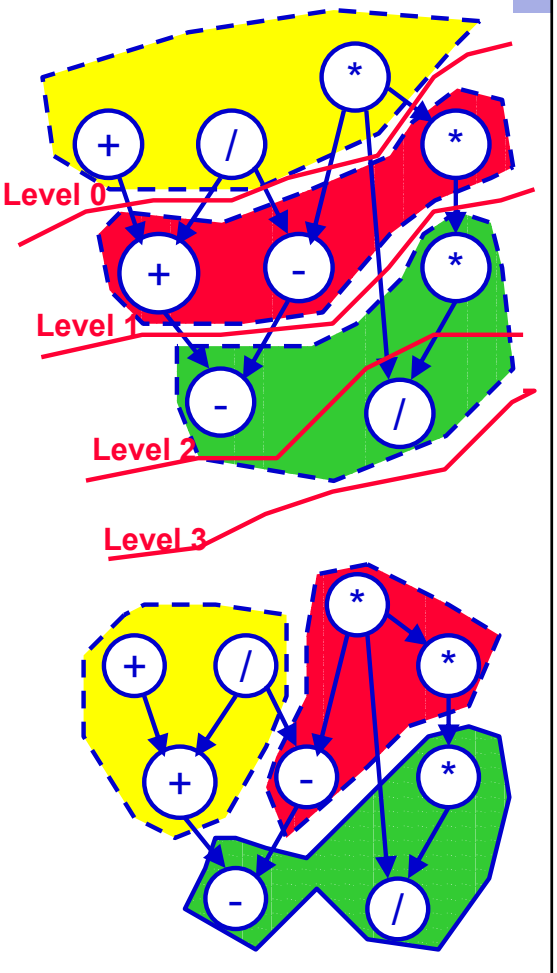
- **Enhancement of the existing methods**
  - **Ex: The List Scheduling (LS) partitioning**
    - **Drawback: "Levelization" (increases data exchange)**
    - **Advantage:**
      - **Fast (linear run-time),**
      - **Local optimization possible**
- **Development of new approaches**
  - **Ex: The Spectral Method**
    - **Drawback: Run-time**
    - **Advantage:**
      - **Good quality**
      - **Reduce data-exchange**



Enhancement of the LS (TPart)
Configuration Switching

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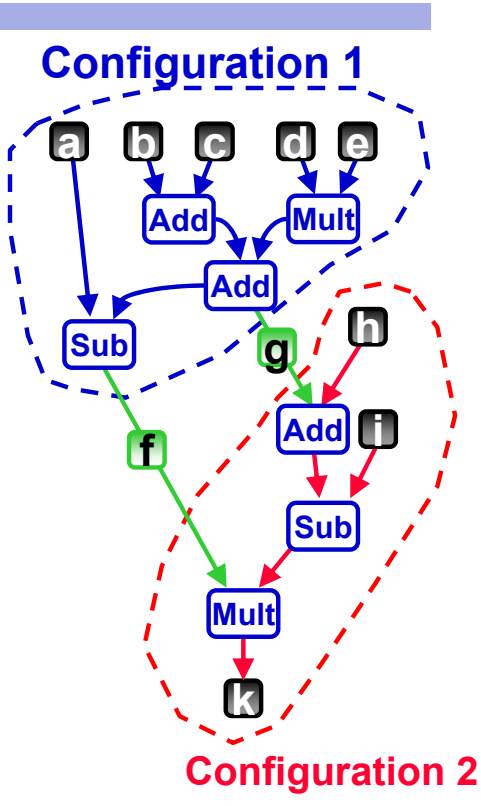

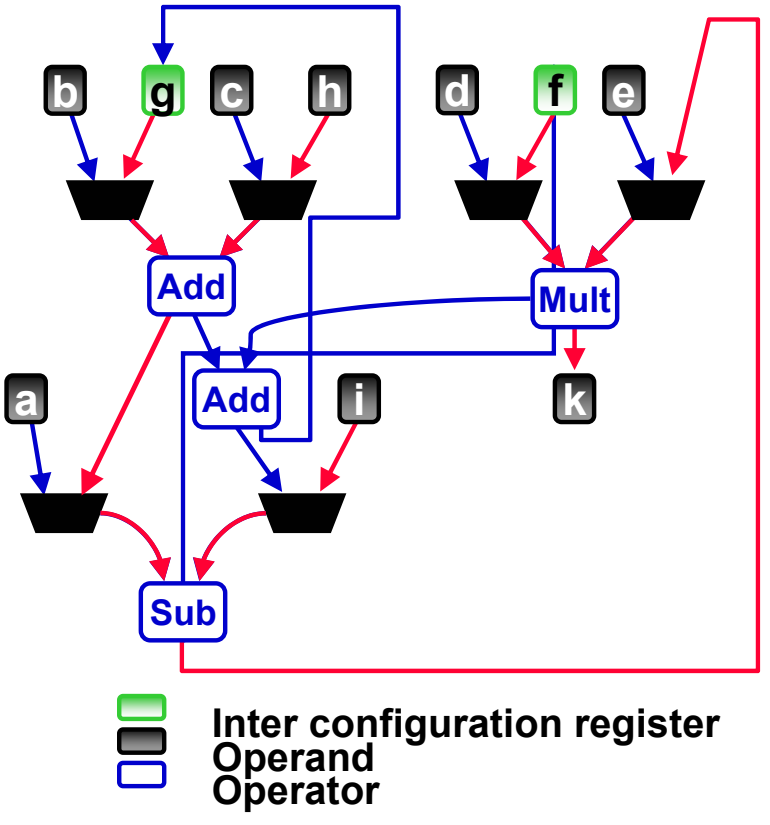

Solution with 2 resident configurations

New approaches (TPart)
The Spectral approach

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- **Goal**
  - Increase the quality of a partitioning
- **2-Steps Method**
  1. Place connected components close to each other (spatial sorting)
  2. Use a recursive bi-partitioning strategy to compute the partitions ➔ configuration graph
- **To solve Step 1**
  - 3-dimensional embedding
    - place the components in an k-dimensional vector space to minimize the sum of the distances between the components

Temporal Partitioning
3-D spectral embedding

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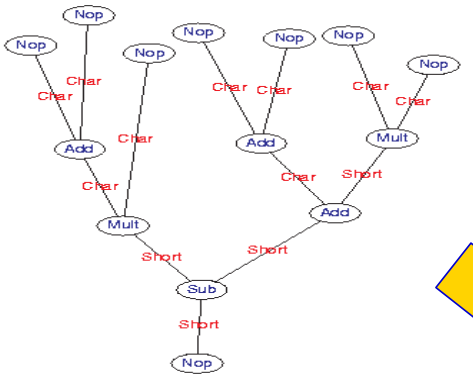


1

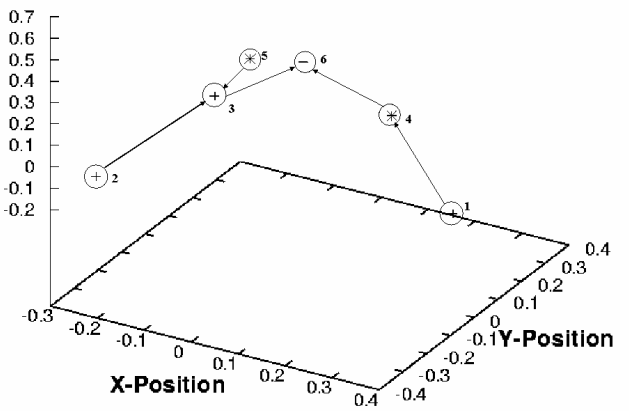
$$\begin{pmatrix}
1&0&0&0&0&0&0&0&0&-1&0&0&0&0\\
0&1&0&0&0&0&0&-1&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&-1&0&0\\
0&0&0&1&0&0&0&0&0&0&0&-1&0&0\\
0&0&0&0&1&0&0&0&0&0&0&-1&0&0\\
0&0&0&0&0&1&0&0&0&0&0&0&-1&0\\
0&0&0&0&0&0&1&0&0&0&0&0&-1&0\\
0&-1&0&0&0&0&0&3&-1&-1&0&0&0&0\\
0&0&0&0&0&0&0&-1&3&0&-1&-1&0&0\\
-1&0&0&0&0&0&0&-1&0&3&0&0&-1&0\\
0&0&0&-1&-1&0&0&0&-1&0&3&0&0&0\\
0&0&-1&0&0&-1&0&0&-1&0&0&3&0&0\\
0&0&0&0&0&0&-1&0&0&-1&0&0&3&-1\\
0&0&0&0&0&0&0&0&0&0&0&0&-1&1
\end{pmatrix}$$

Z-Position(time)

$$\lambda_6 = 0.112586$$
$$\lambda_3 = 0.267949$$
$$\lambda_1 = 0.438447$$

$$\begin{pmatrix}0.0410593\\-0.152761\\0.225048\\-0.241072\\-0.241072\\0.355147\end{pmatrix}\quad\begin{pmatrix}0.0\\0.0\\0.0\\0.325058\\-0.325058\\0.0\end{pmatrix}\quad\begin{pmatrix}0.34188\\0.0749482\\0.191984\\-0.0749481\\-0.0749483\\-0.191984\end{pmatrix}$$

3



Generation of Partitions

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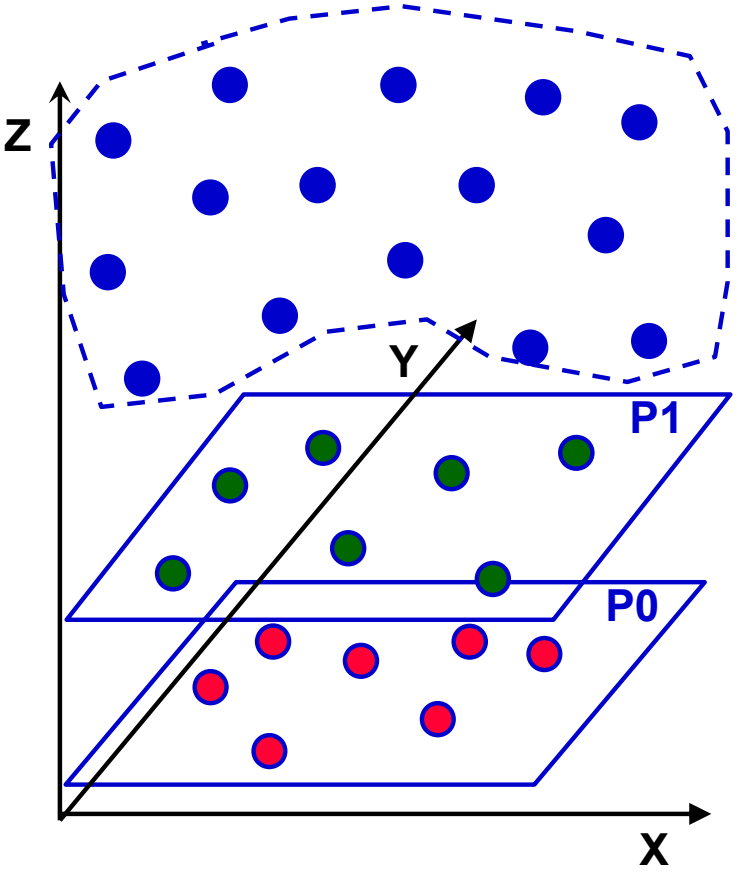
- Incremental generation of $P_0, P_1, ..., P_r$
- Select components along the Z axis and put them into the actual partition until the size exceeds that of the FPGA
- Recursive bi-partitioning
- Bipartition may be cyclic
- Post-processing via modified Kernighan-Lin Algorithms



Temporal Placement
Partial Reconfiguration

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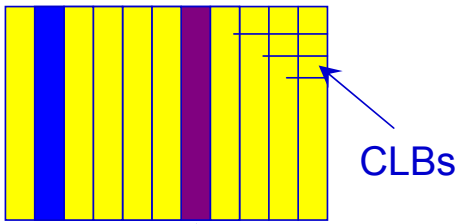
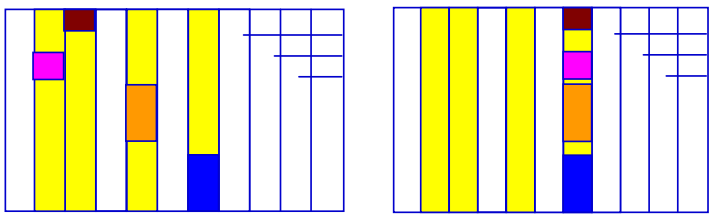
- **In the Xinlinx Virtex FPGA**
  - **Partial reconfiguration via Frames Replacement**
- **Clustering of components is important**
  - **Reduce the amount of configuration data**
  - **Avoid to disturb running Components**
  - **Resource utilization ?**
- **Development of Clustering approaches**
  - **Enhancement of the existing methods. (Ex LS)**
  - **Development of new approaches (Ex Spectral)**





4 frames to configure

One frame to configure

Temporal Placement
Placement of clusters

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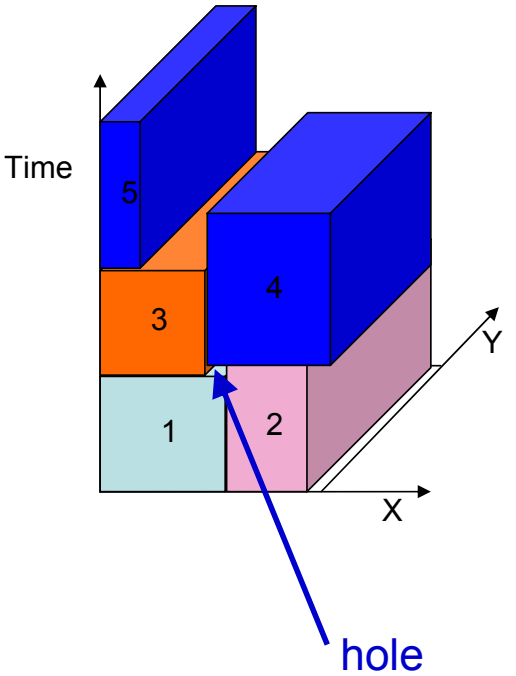
- First-Fit Temporal placement
  - Select a new cluster C_{new} with no predecessor
  - Select a running cluster C_{top} with minimum run-time
  - Place the C_{new} on top of C_{top}
- Drawback
  - Production of Holes



Temporal Placement
Placement of clusters

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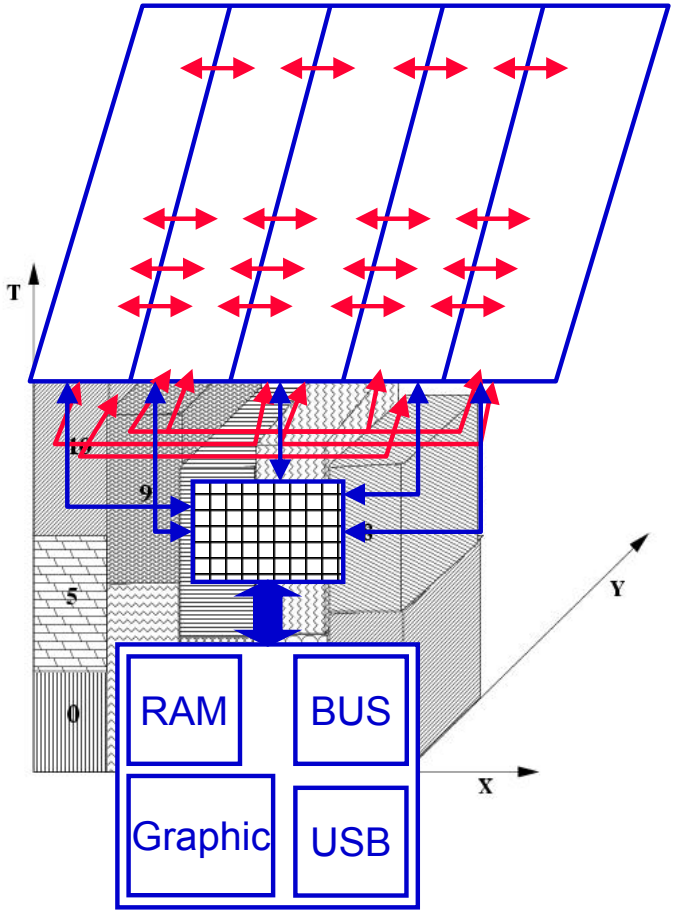
- Divide the FPGA in blocks
  - Each block occupy a set of columns
  - Clusters will occupy the same surface (block)
- First-Fit Temporal placement
  - Select a new cluster C_{new} with no predecessor
  - Select a running cluster C_{top} with minimum run-time
  - Place the C_{new} on top of C_{top}



Temporal Placement
Level-based Clustering

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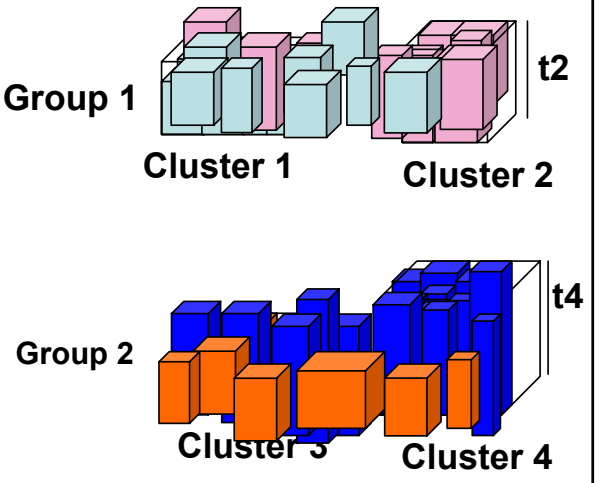
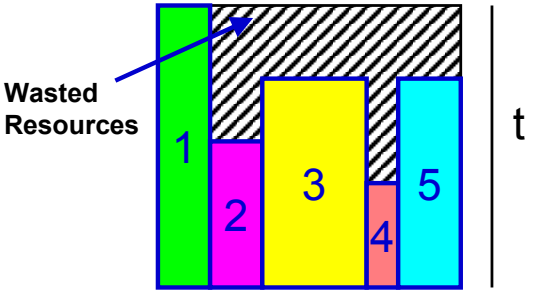
- **2-Steps Method**
  1. Group the Components of the Graph according to their level-number
  2. For each group, place components with "equal run-time" in the same cluster
- **Drawback**
  - "Levelization" (increase data exchange)
- **Advantage**
  - Fast (linear run-time)
  - Less amount of Wasted resource

$$wr(C) = \sum_{v_i \in C} (t(C) - t_i) * a_i$$





Temporal Placement
Spectral-based Clustering

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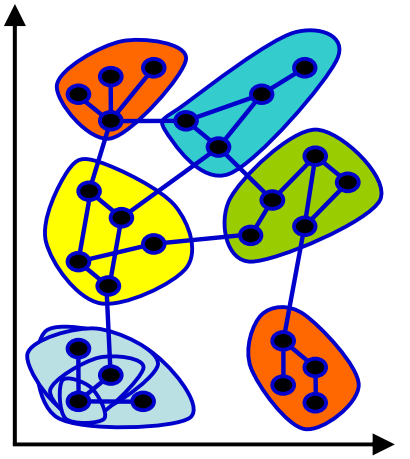
- **2-Step Method**
  - 2 dimensional spectral embedding
  - Partitioning via cluster growth

  1. Build a new cluster C_{new}
     a) Select next node V_{act} and place in C_{new}
     b) Place the nearest node to C_{new} in C_{new}
     c) if (size (C_{new}) ≤ size (FPGA)) goto 1.a) ; else goto 1.b) ;
     d) if all nodes assigned exit; else goto 1;



- **Drawback**
  - Wasted Resources.
    - Can be limited by capture the time factor
  - High run-time *($O(n^3)$)*
- **Advantage**
  - Less data exchange

Tool integration

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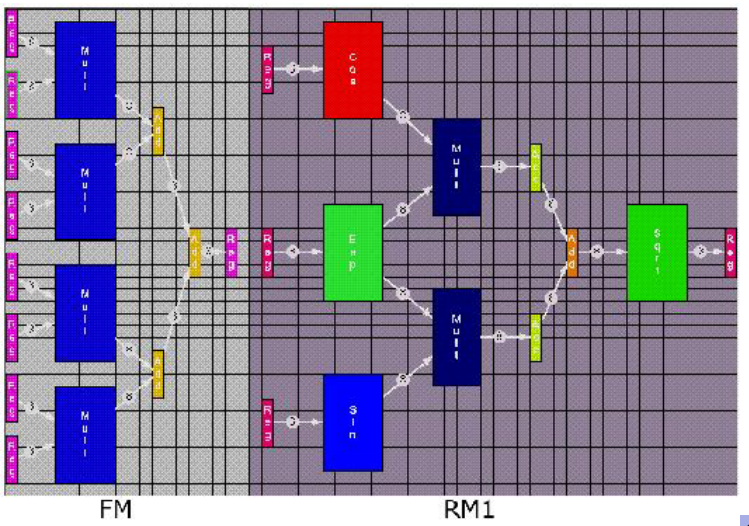
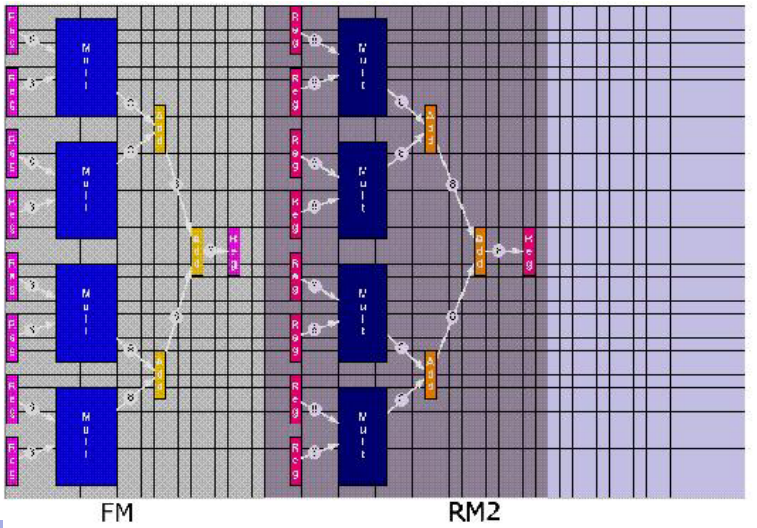
- Specification of the temporal partitioning and placement in the design process (VHDL, Handel-C, System C)
- Co-simulation, synthesis and co-verification of different modules
- Generation of partitions or clusters





Previous work (Up to now)

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- Temporal partitioning and placement for Directed acyclic graphs:
- Performance measurement:
  - Quality ⇔ data exchange reduction
  - Wasted resources ⇔ efficient use of the FPGA resources
- Approaches:
  - List-scheduling enhancement
  - Spectral methods
- Graphical specification of temporal placement in a tool

New investigations

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- Temporal partitioning and placement for CDFGs:
- Performance measurement:
  - Quality ⇔ data exchange reduction
  - Wasted resources ⇔ efficient use of the FPGA resources
  - Overall run-time
- Tradeoff
  - Run-time vs. area
- Enhancement of the existing approaches:
  - List-scheduling
  - Spectral methods
- Textual and graphical specification

Cooperation

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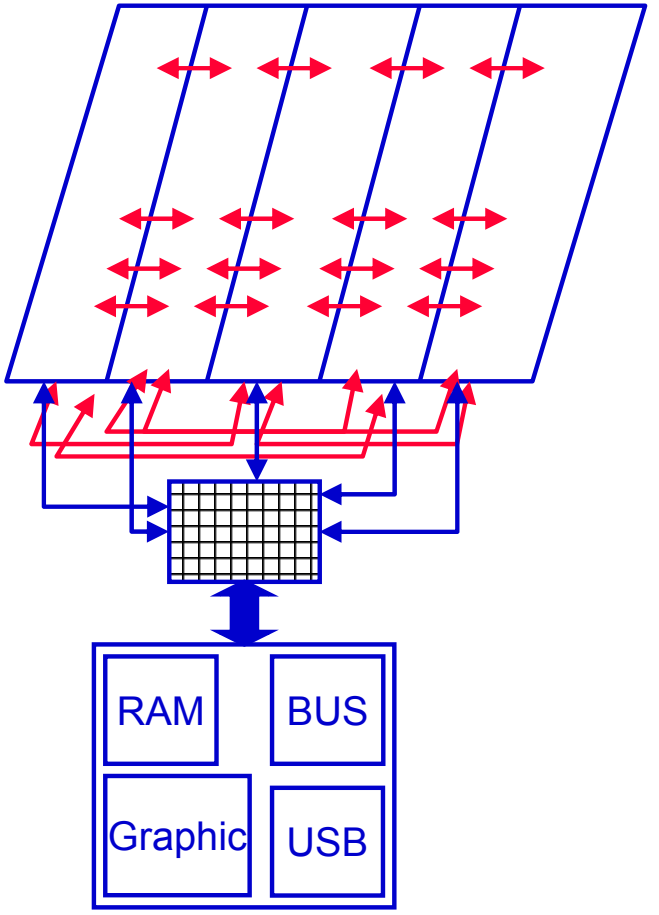
- **Prof. Dr. W. Hardt**
  Interface Specification and synthesis
  - Interface definition
  - Interface synthesis
  - Tool integration
- **Prof. Nebel, OFFIS**
  - Application
    - Image and song
  - Synthesis (Prof. Nebel)
    - Integration into the ODETTE environment



Conclusion

- Goal
- Definition of Temporal partitioning and Temporal placement
- Solution approaches for temporal partitioning and placement
- Tool Integration
- Previous work and new investigations
- Cooperation

Thanks for your attention