

K-PACT: Kernel Planning for Adaptive Context Switching - A Framework for Clustering, Placement, and Prefetching in Spectrum Sensing

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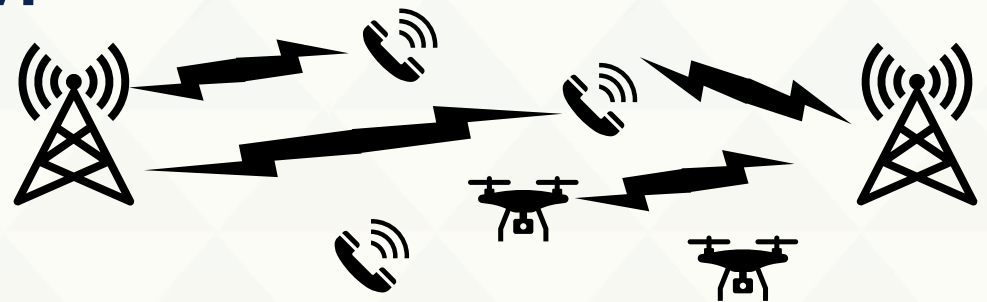
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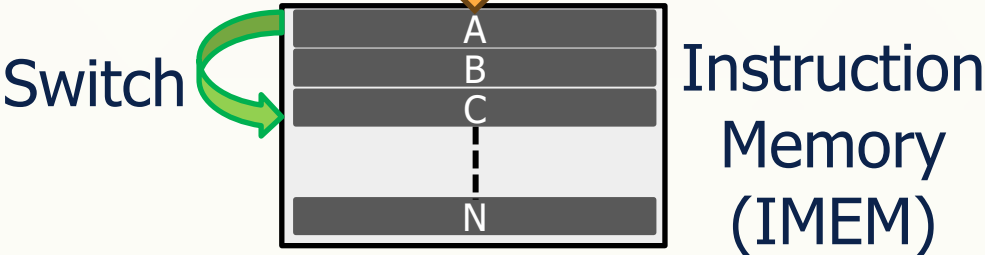
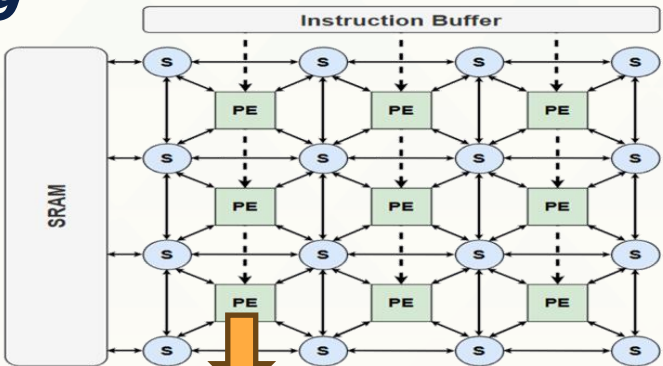
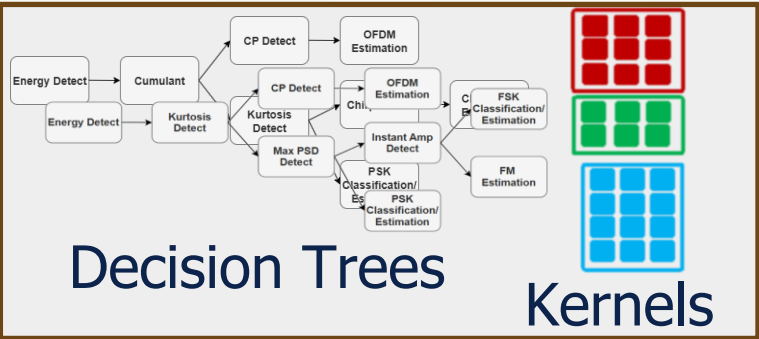
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Motivation and Contribution

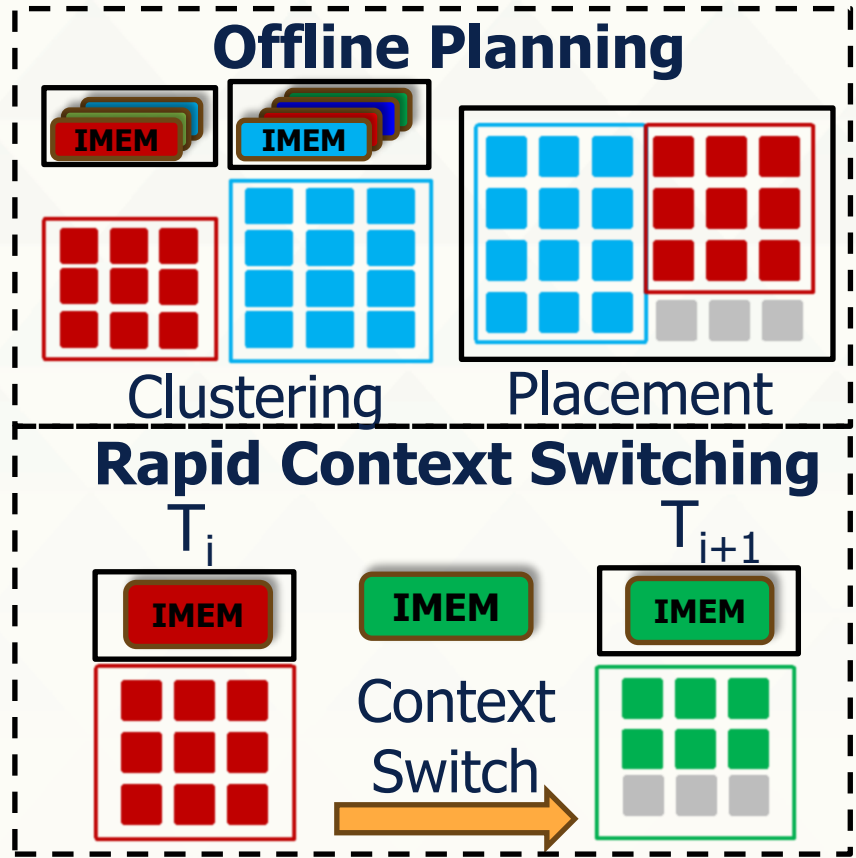
Advanced spectrum sensing classify signal types within an environment



Seamless reconfiguration and parallel workload processing are key enabler for real-time spectrum sensing



Intelligent PE allocation and IMEM management strategies are needed to mitigate costly overheads



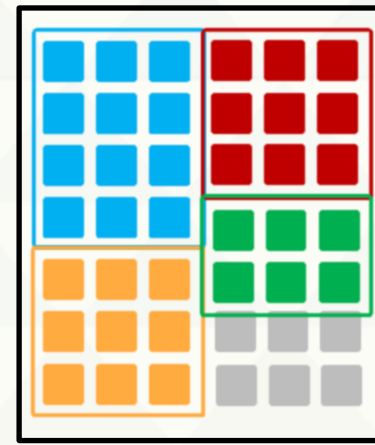
Clustering and Placement Approach

$$\mathcal{K}_i \in \mathcal{C}_j \iff (e_{i-1} < s_i) \wedge \sum_{\mathcal{K}_k \in \mathcal{C}_j} I_{\text{req}}(\mathcal{K}_k) < I_{\text{lim}},$$

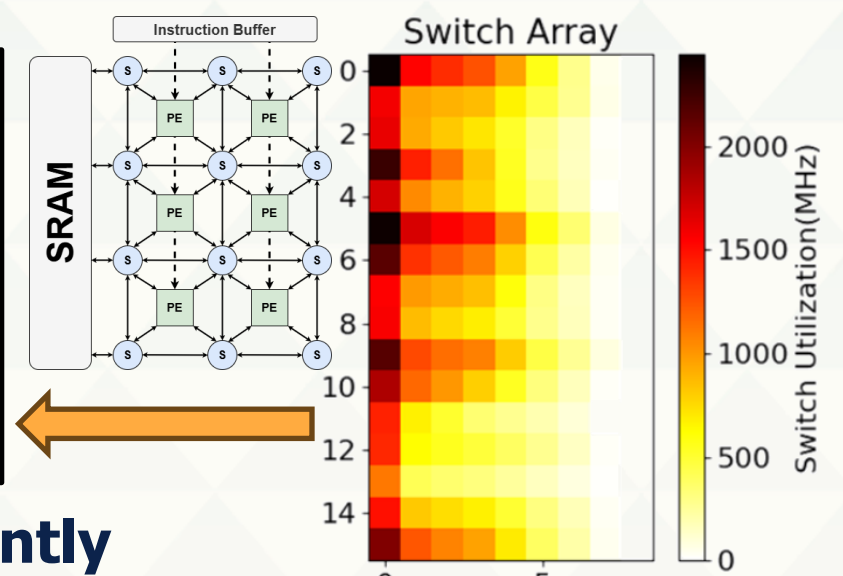
$$\forall \mathcal{K}_i^{(s_i, e_i)} \in \{\mathcal{K}_1, \dots, \mathcal{K}_N\}, \quad \forall \mathcal{C}_j \in \{\mathcal{C}_1, \dots, \mathcal{C}_M\}$$

Objective Statement:

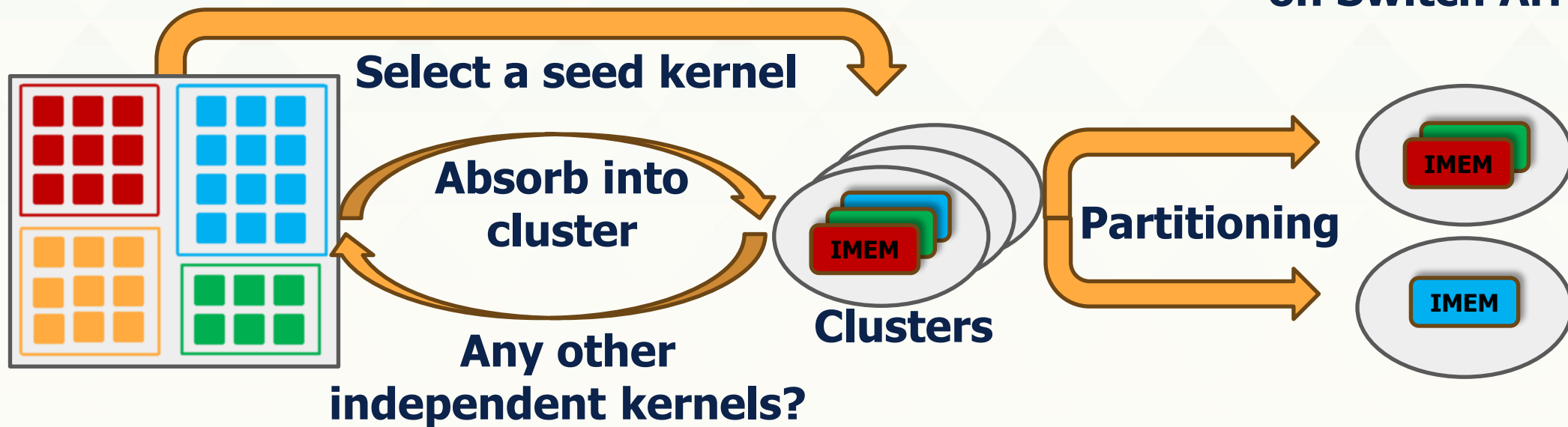
- Group N kernels into M clusters
- Satisfy an IMEM size constraint
- Minimize total number of clusters



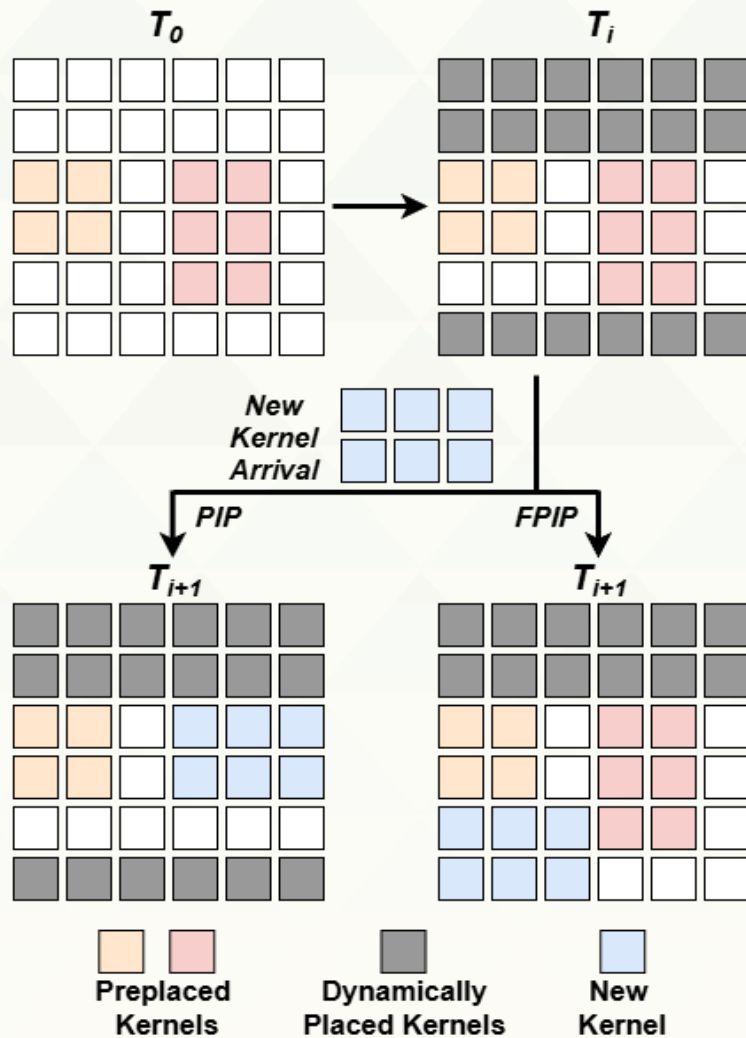
**Prioritize frequently
accessed head nodes**



**Routing Congestion
on Switch Array**



Pre-Initialization Strategies



- **Pre-initialized Placement (PIP)**
 - dynamic resource manager can evict the pre-initialized kernels
 - diminishes the benefits of profiling-guided pre-initialization
- **Fixed Pre-initialized Placement (FPIP)**
 - dynamic resource manager cannot evict the pre-initialized kernels
 - maintains pre-initialization and fully leverages rapid switching capability

No/Soft/Hard Switch

No Switch

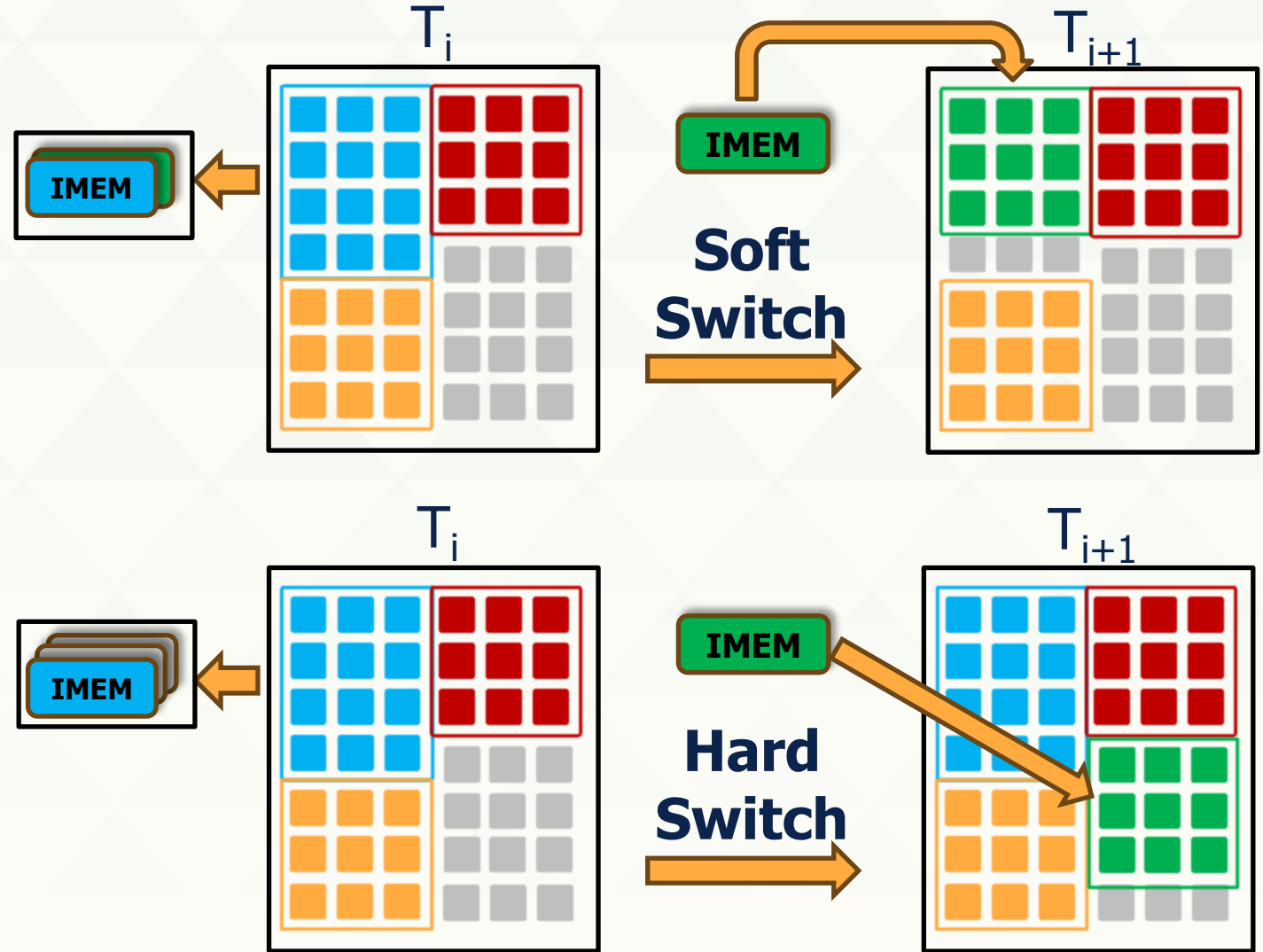
- Kernel is already loaded in IMEM
- Instantaneous switch

Soft Switch

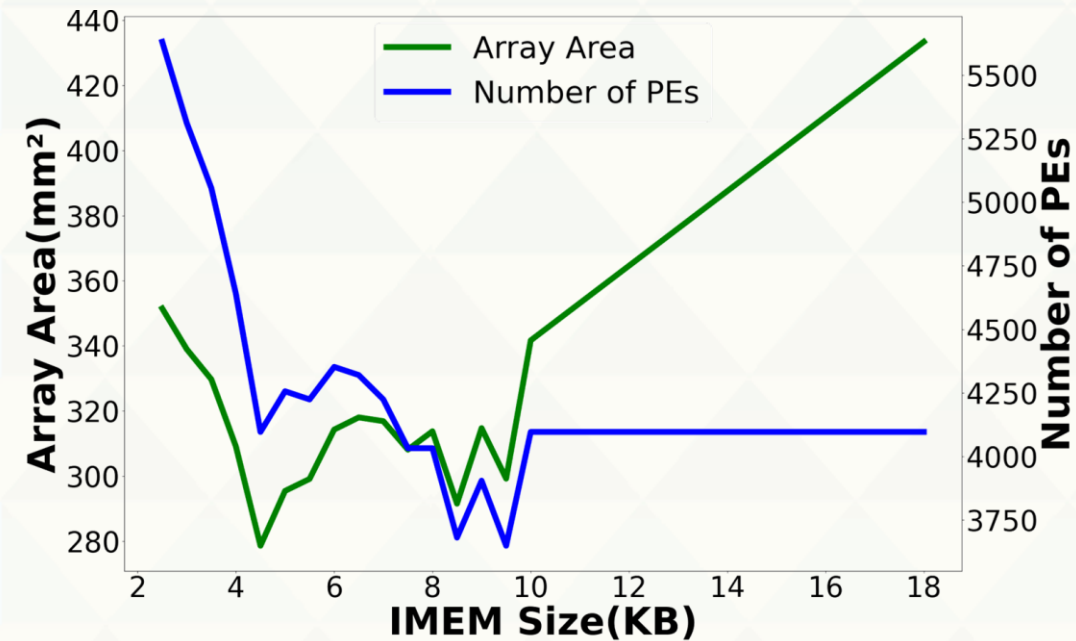
- New kernel binary exists in IMEM
- *Cost*: Cluster search
- Low switching latency

Hard Switch

- New kernel binary is not in IMEM
- *Cost*: Cluster search, allocation, eviction
- High switching latency



Experimental Setup



Optimal Configuration

- 4.5 KB IMEM size
- 4096 PEs
- 278.56 mm²

Simulation Platform

- Open-source domain-specific system-on-chip simulator (DS3)*

Scheduling Modes

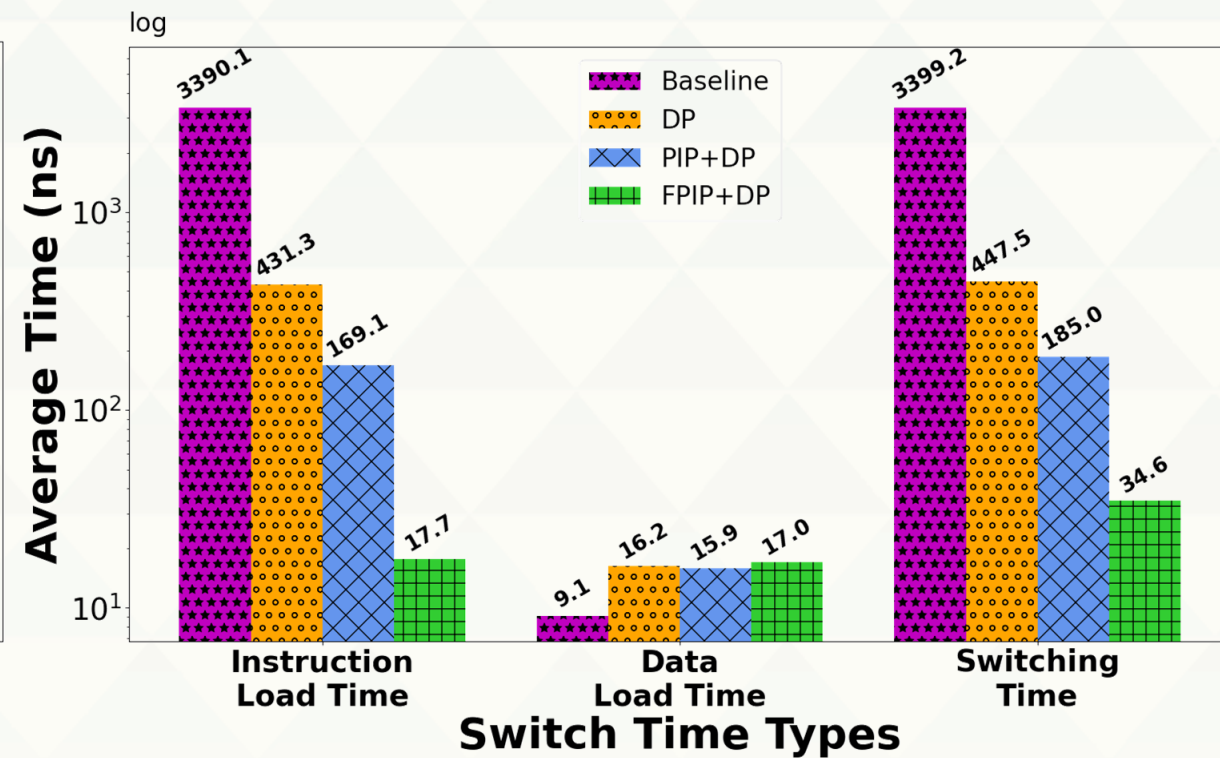
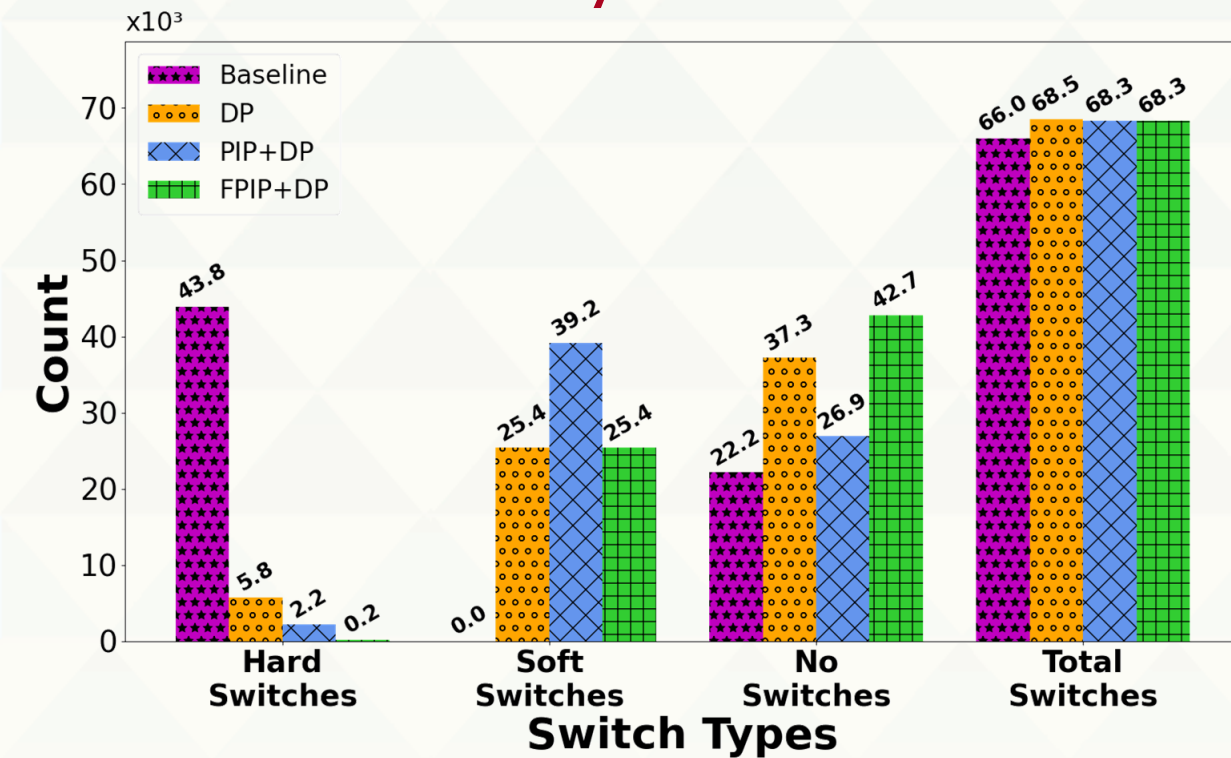
- **Baseline:** performs only hard switches
- **Dynamic Placer:** forms clusters and execute soft switches
- **Pre-initialized Placement+Dynamic Placer:** evicts kernels from the preplaced regions
- **Fixed Pre-initialized Placement+Dynamic Placer:** preserves preplaced kernels

Metrics

- Switch Count/Time
- Scheduling Time
- Execution Time per Tree



Switch Time Analysis

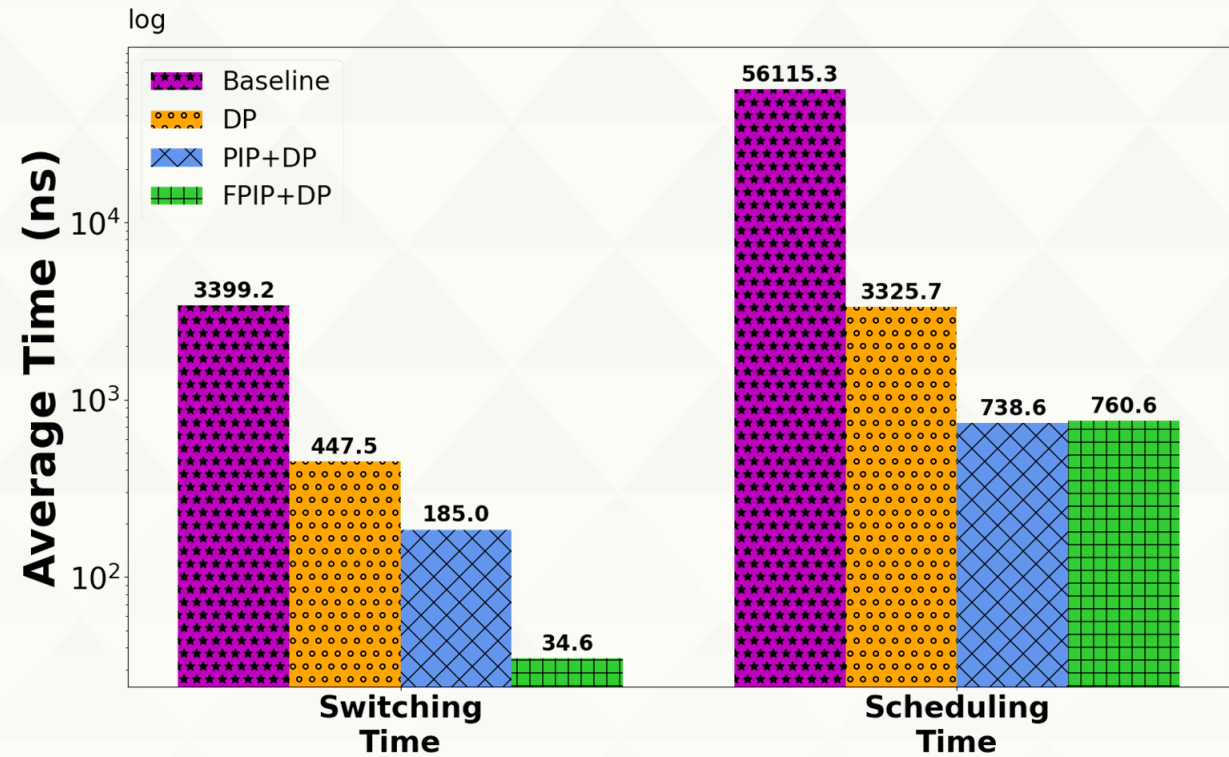


- 207.81x reduction in hard switch count
- PIP+DP -> high utilization of soft switches
- FPIP+DP -> extensive use of no switches
- 191.51x reduction in instruction load time
- Data load time becomes the bottleneck
- 98.24x reduction in overall switching time

Pre-initialized placement exploits rapid switching, reducing expensive off-chip fetches



Scheduling and Execution Time Analysis



Scheduling Time:

- Cluster Search, Placement/Routing Decisions
- 75.97x scheduling time improvement
- High eviction cost for FPIP+DP

Average Execution Time Per Tree

| Execution Approach | Execution Time (us) | Speedup w.r.t <i>Baseline</i> | Speedup w.r.t <i>DP</i> |
|--------------------|---------------------|-------------------------------|-------------------------|
| Baseline | 431.622 | 1x | N/A |
| DP | 9.943 | 43.40x | 1x |
| PIP+DP | 3.865 | 111.67x | 2.57x |
| FPIP+DP | 3.247 | 132.92x | 3.06x |

- 132.92x execution time speedup
- Significant scheduling overhead

Systems with rapid switching capabilities need efficient scheduling strategies to maximize the throughput

Conclusion and Future Work

- Spectrum sensing requires high throughput and instantaneous detection capability to handle highly dynamic spectrum environments.
- We present K-PACT, a planning tool that assigns independent kernels to PEs with separate IMEM banks, enabling fast, conflict-free context switching for kernels that do not execute concurrently.
- Simulation results show that K-PACT reduces the
 - ***instruction load time by 191.53×***
 - ***overall execution time of a subband by 132.92×***
- This approach can be generalized beyond spectrum sensing, meeting the needs of multi-context and rapidly changing workloads.
- As future work, we aim to design routing-aware clustering and placement algorithms with efficient scheduling heuristics to further enhance performance through faster context switching.



Thank You!



UA - RCL Webpage

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Questions?



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