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ObeSense RTD 2013

FNSNF

Hardware / Software Optimizations for Efficient Embedded Digital Signal Processing in Wireless Body Sensor Nodes

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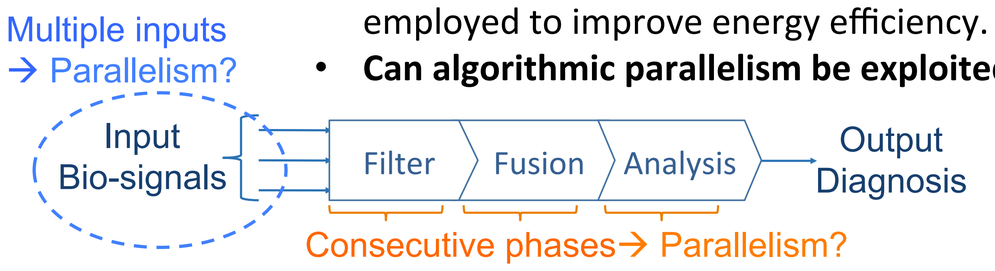
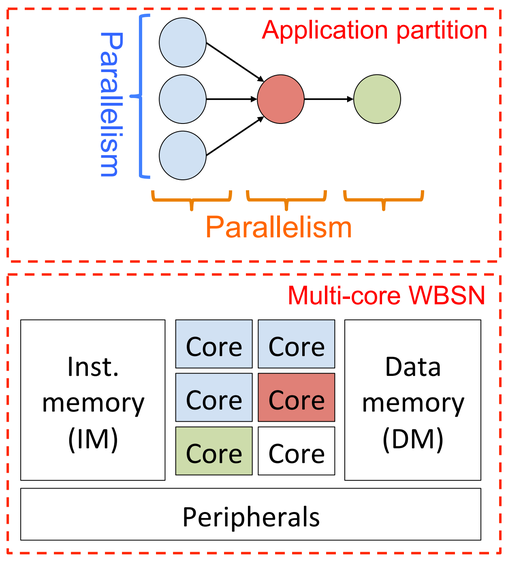
Wireless Body Sensor Nodes (WBSNs) in Healthcare

- **WBSNs** are miniaturized devices able to acquire, process and transmit bio-signals (ECG, EMG, blood pressure movements…)
  - ↑ Wearable, unobtrusive, inexpensive
  - ↓ Limited resources and autonomy
- On-board Digital Signal Processing (DSP) is employed to improve energy efficiency.
- **Can algorithmic parallelism be exploited?**



New Trend: Multi-core WBSN for Efficient DSP

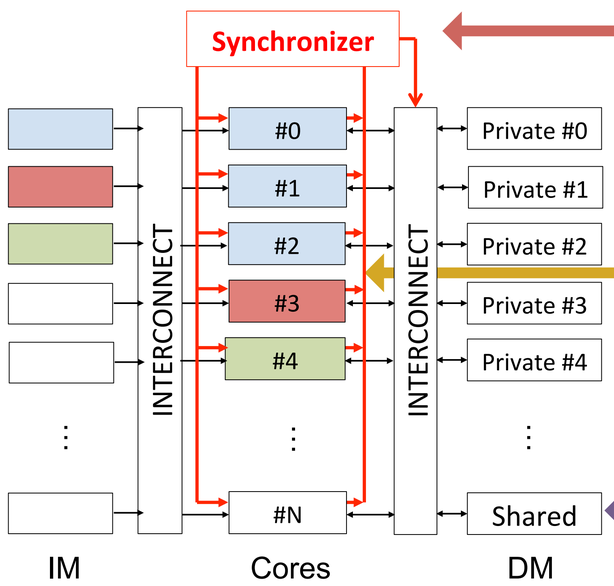
- Workload is divided into subtasks by pipelining phases and performing SIMD execution over several bio-signals
  - → Each subtask is executed in a core
  - → **Voltage frequency scaling (VFS)**
- Challenges
  - Data-dependent branches (SIMD)
  - Data and control flow among phases
- Lack of efficient mechanism for
  - Re-synchronization to maximize SIMD
  - Producer-consumer notification



Proposed Solution: Lightweigth HW / SW Mechanism for Code Synchronization

Multi-core WBSN (based on [1])

- RISC ultra-low power processors
- **Multi-banked** IM and DM + **shared and private** DM
  → Minimize memory conflicts
- Logarithmic combinational interconnect [3] with arbitration capabilities
- **Broadcasting**: Simultaneous request of the same address are merged into a single memory access
  → Memory energy efficiency



Synchronizer unit:
- Stalls and wakes-up cores to orchestrate execution
- Guaranties re-synchronization

Instruction Set Extension (ISE):
- SLEEP, SINC, SDEC and SNOP
- Mark synchronization events and modify synchronization points

Synchronization points:
- Store run-time information for each synchronization event
- Reserved space in shared memory

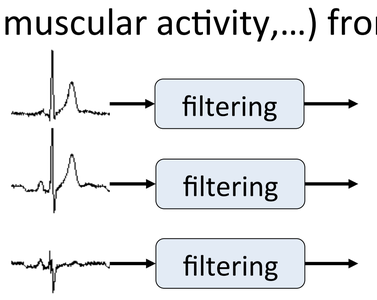
Steps to adapt existing bio-medical applications

1. **Partitioning:** Identify algorithmic phases (producer-consumer) and potential parallel computations (SIMD)
2. **Instruction insertion:** Implement re-synchronization and producer-consumer relations with the specific ISE
3. **Code mapping:** Cores performing SIMD share the shame IM bank

Benchmarks: Embedded Electrocardiogram (ECG) Applications for WBSNs

Multi-lead ECG filtering (3L-MF) [3]

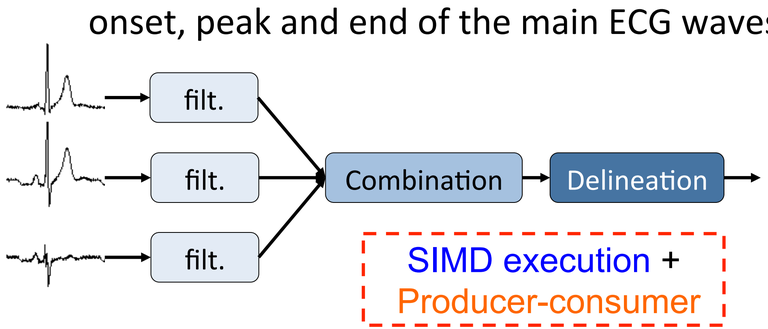
- Remove unwanted artifacts (perspiration, muscular activity,…) from multiple ECG signals



Only SIMD execution

Multi-lead ECG delineation (3L-MMD) [4]

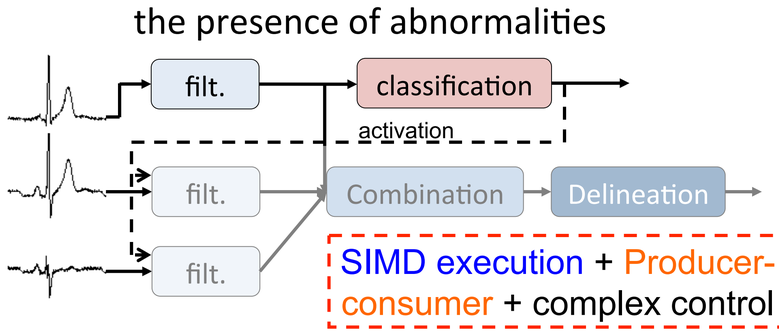
- Combines multiple filtered signals and finds onset, peak and end of the main ECG waves



SIMD execution + Producer-consumer

Heart-beat classifier (RP-CLASS) [5]

- Performs multi-lead delineation only in the presence of abnormalities



SIMD execution + Producer-consumer + complex control

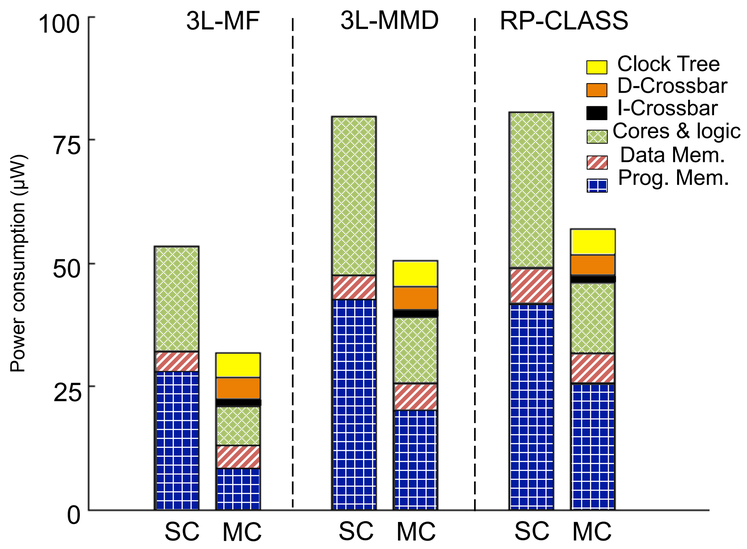
Experimental Results

Two considered systems:

- Synchronized multi-core WBSN (MC)
- Equivalent single-core WBSN (SC)

Evaluation Framework

- RTL implementation
- SystemC cycle-accurate simulator
- Custom compilation tool-chain
- Power model derived from post-layout simulations



Overhead	3L-MF	3LMMD	RPCLASS
Code size	2,6 %	0,9 %	0,7 %
Run-time	1,7 %	1,0 %	0,6 %

Conclusions

- Multi-core WBSN are more energy efficient than single-core equivalents if they are **properly synchronized**
  → Up to **40% less power consumption** (3L-MF)
  → **Very low overhead (< 3%)** due to synchronization
- Synchronization + **Broadcasting** = Memory energy efficiency
  → **40% less accesses** to IM and **3.7% less accesses** to DM
- SIMD + Workload division → Lower clock constraint → **VFS**
  → **15% Reduction of System V_{DD}**

REFERENCES:

[1] Dogan, et al., "Low- power processor architecture exploration for online biomedical signal analysis," IET-CDS 2012.
[2] Rahimi, et al. "A fully-synthesizable single-cycle interconnection network for Shared-L1 processor clusters" DATE'11
[3] Y. Sun et al., "ECG signal conditioning by morphological filtering," Computers in Biology and Medicine, 2002.
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[5] Braojos et al., "A methodology for embedded classification of heartbeats using random projections," in DATE'13