MONDRAGON UNIBERTSITATEA

GOI ESKOLA POLITEKNIKOA

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A Low-Cost FPGA-based Embedded Fingerprint Verification and Matching System

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Index

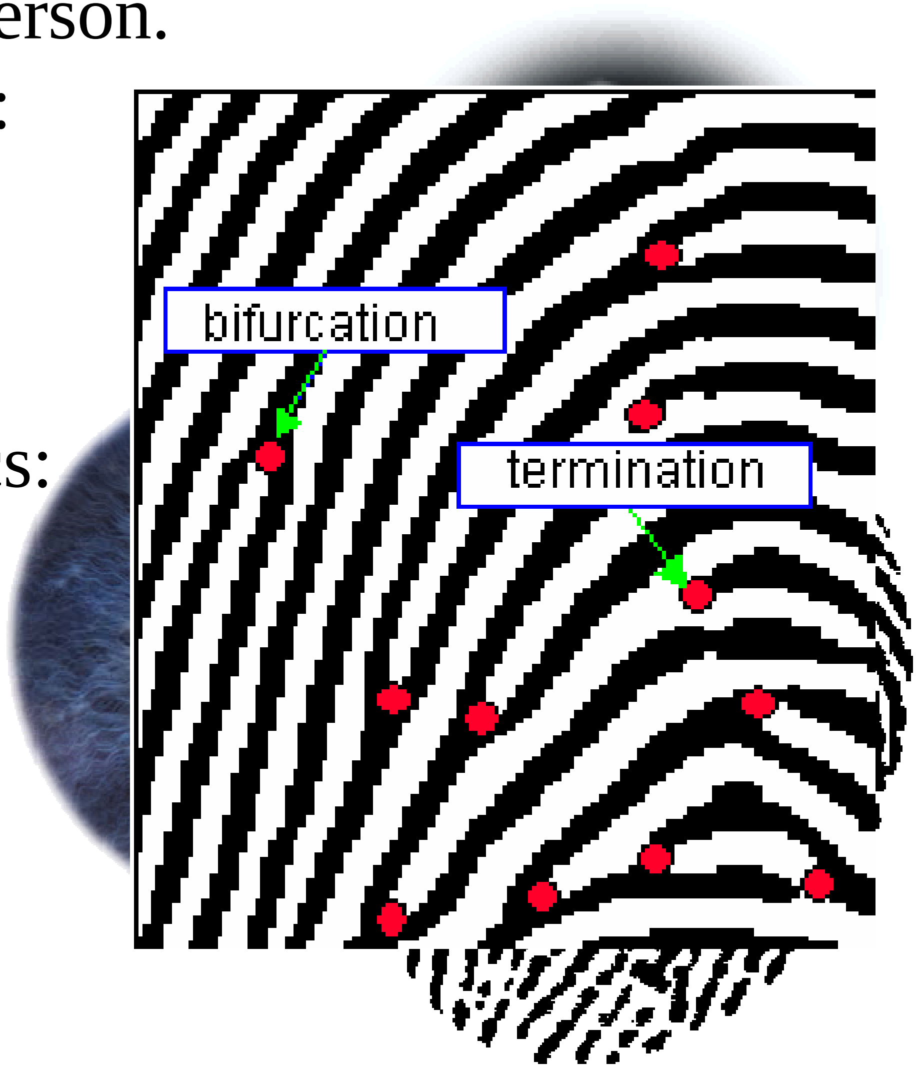
- Introduction
- Software Architecture
- Hardware Architecture
- Conclusions

Index

- **Introduction**
- Software Architecture
- Hardware Architecture
- Conclusions

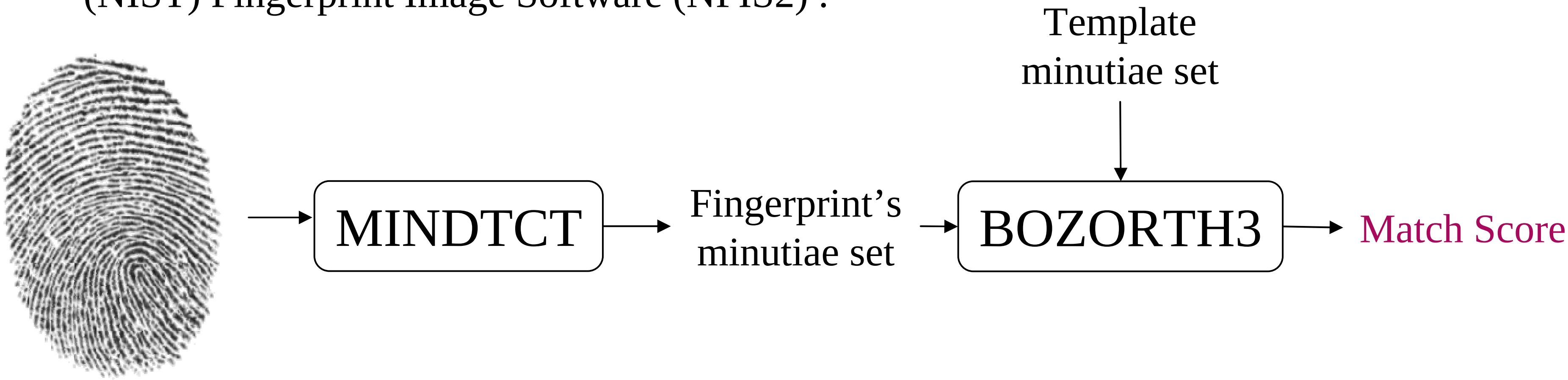
Biometrics

- Uses some **unique** behavioural or physiological characteristics to identify a person.
- Behavioural characteristics:
  - Signature
  - Gait
  - Typing pattern
- Physiological characteristics:
  - Fingerprints
  - Facial Patterns
  - Hand Measurements
  - Eye Retinas



System Overview

- Software
  - Based on the packages from the National Institute of Standard and Technology's (NIST) Fingerprint Image Software (NFIS2) .



- Hardware
  - Spartan3 family FPGA
    - Leon2 32-bit Sparc Processor
    - Floating Point Unit (FPU)
    - Hardware co-processor
  - Fujitsu MBF200 fingerprint sensor

Index

- Introduction
- **Software Architecture**
- Hardware Architecture
- Conclusions

Software Implementation on a Leon2 Platform

- Custom version of the MINDTCT and BOZORTH3 packages (NIST2).
  - Only those modules required for XYT formatted minutiae output set generation have been used.
  - Input fingerprint image format modified → RAW
  - Used fingerprint images fulfil the conditions set for an optimum performance
    - 500 dpi
    - 256 greyscale
- Bare-C Cross-Compiler
- GRMON debug monitor

Minutiae Extraction Algorithm

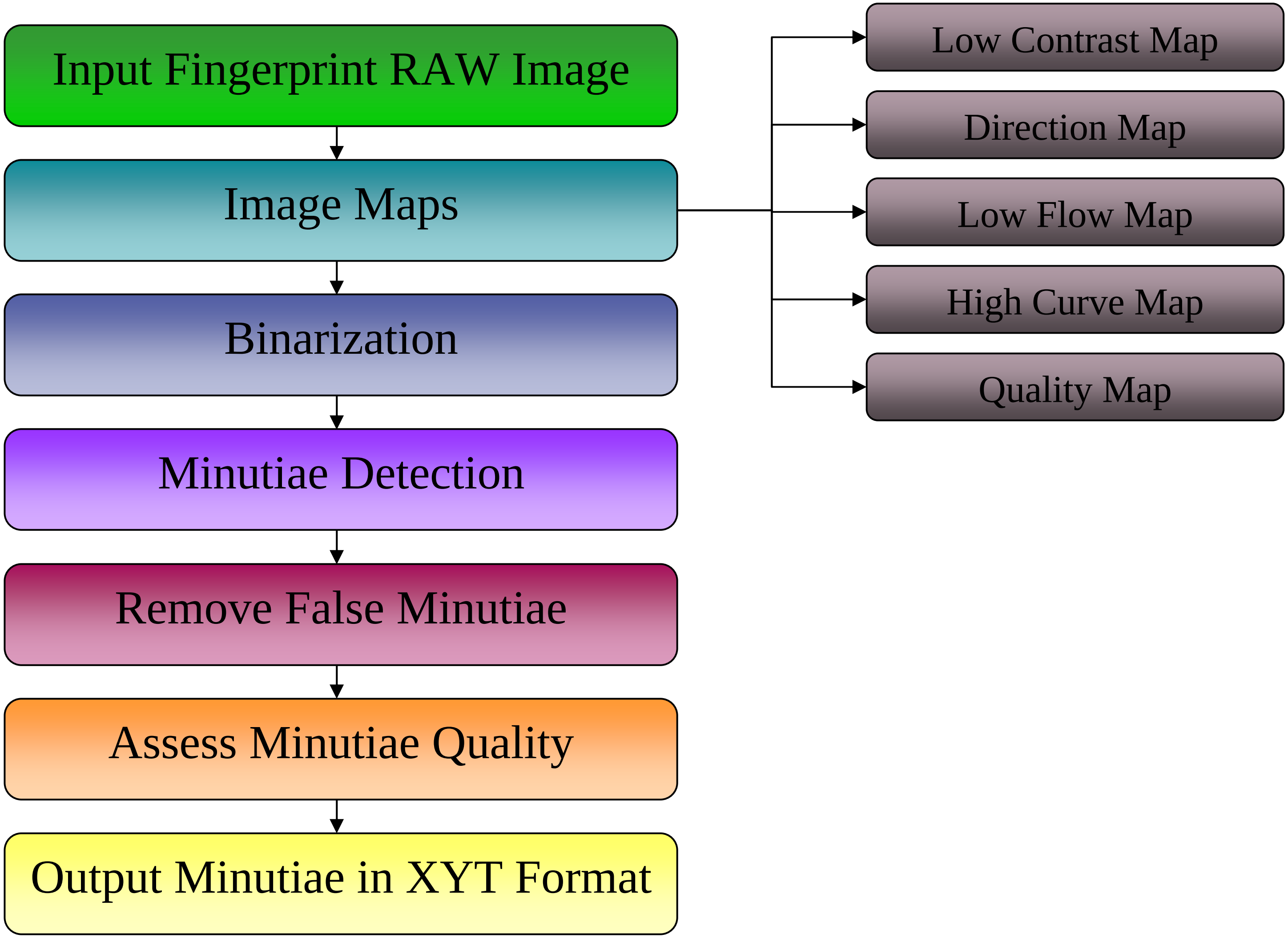
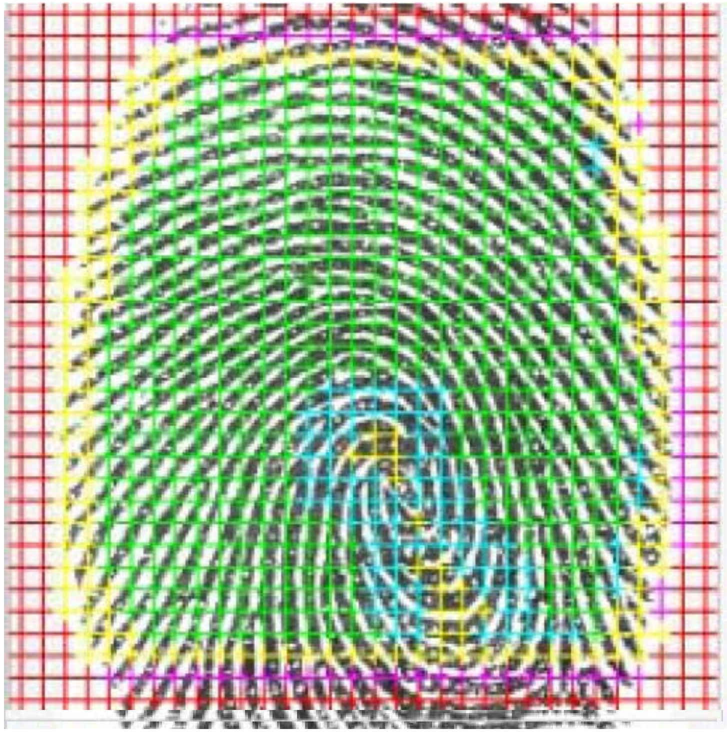


Image Maps

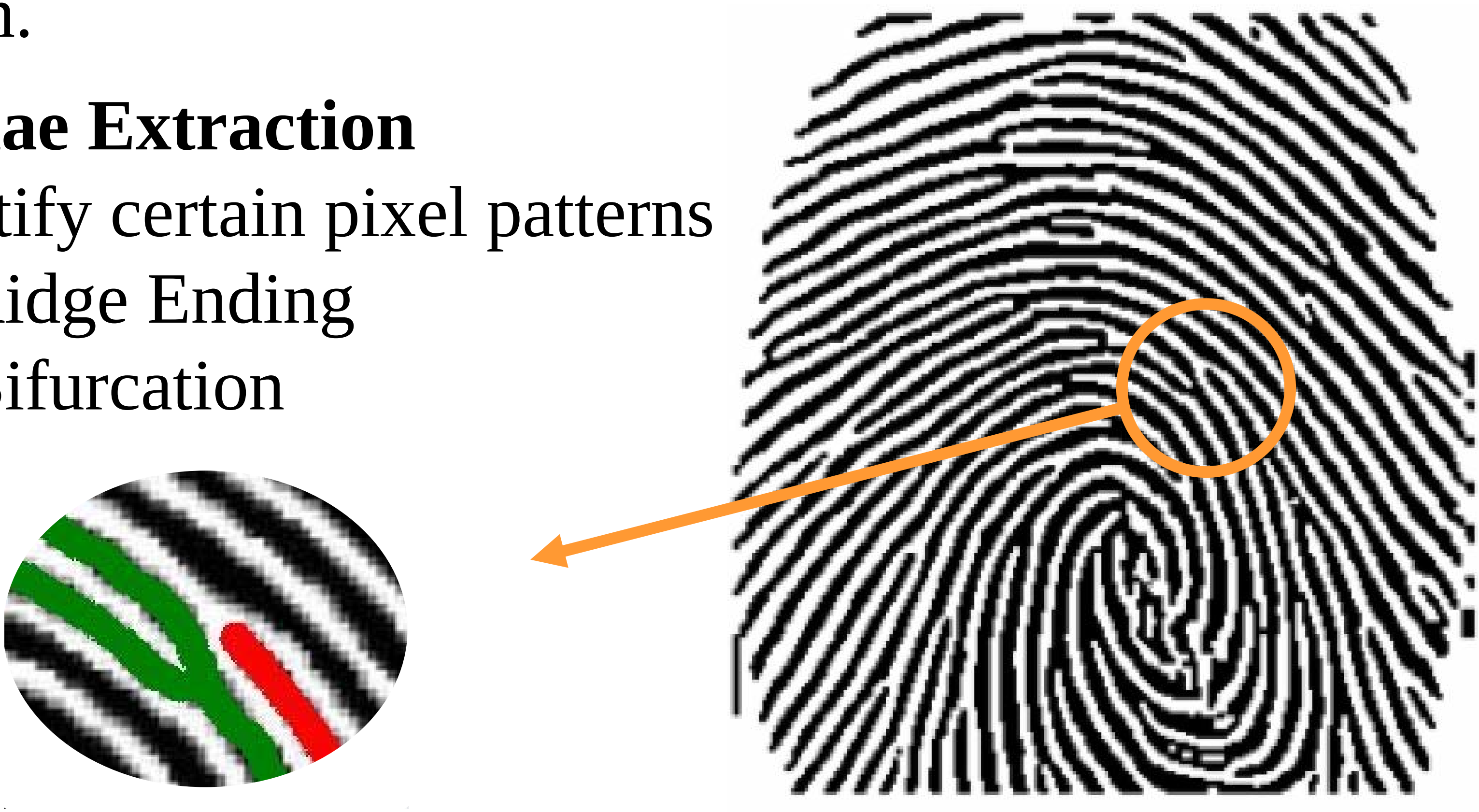
- **Low Contrast Map**: Marks low contrast areas in the image.
- **Direction Map**: Represents the main ridge flow direction.
- **Low Flow Map**: Identifies image areas with a weak ridge structure.
- **High Curve Map**: Flags high curvature areas in the image.
- **Quality Map**: Assigns a quality level to each block in the image.

● Poor quality
● Fair quality
● Good quality
● Very good quality
● Excellent quality



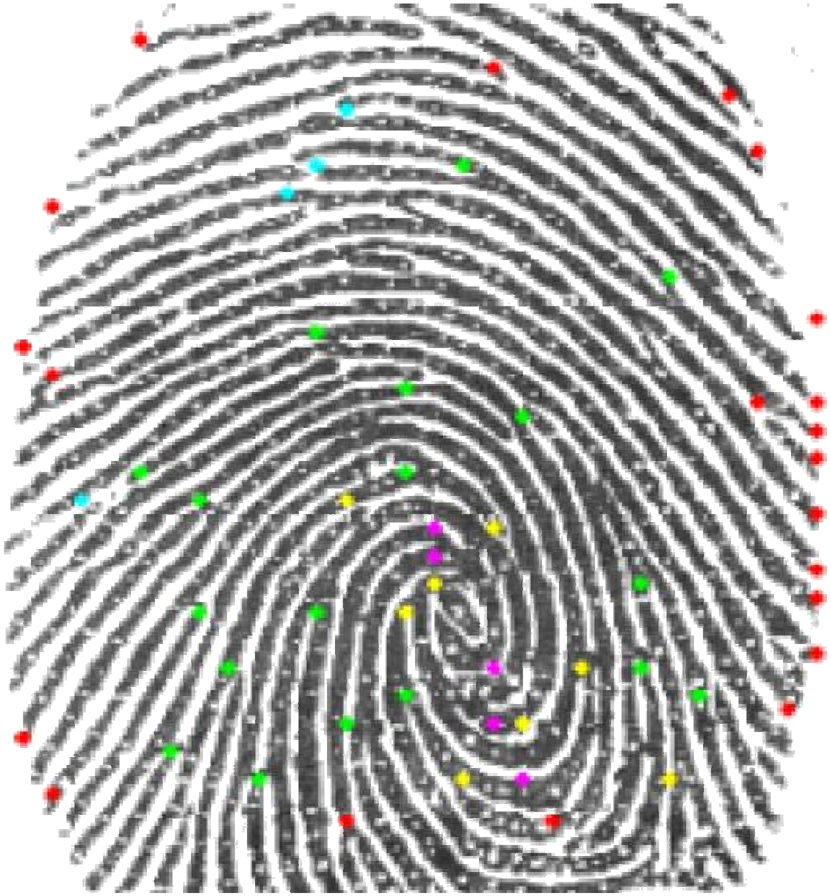
Binarization & Minutiae Extraction

- **Binarization**
  - A pixel is assigned a binary value based on the ridge flow direction associated with the block the pixel is within.
- **Minutiae Extraction**
  - Identify certain pixel patterns
    - Ridge Ending
    - Bifurcation



False Minutiae Removal & Quality Assessment

- **Remove False Minutiae**
- **Assess Minutia Quality**
  - Two factors are combined to produce a quality measure:
    - Quality Map
    - Pixel Intensity Statistics



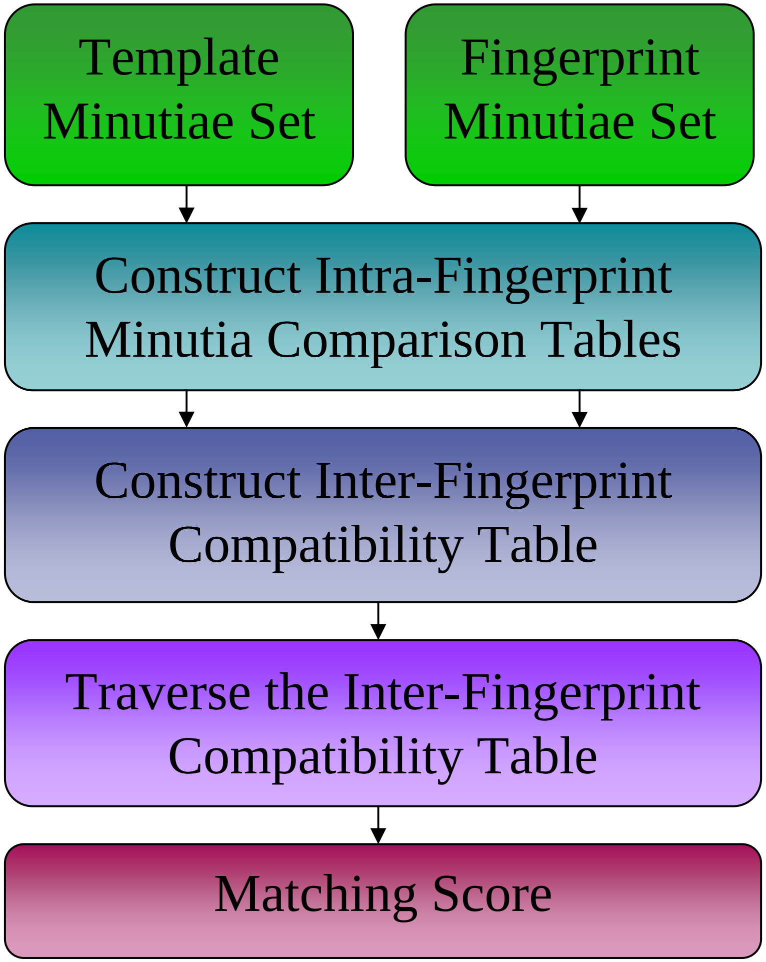
● Poor quality
● Fair quality
● Good quality
● Very good quality
● Excellent quality

Matching Algorithm

- **Bozorth3**
  - Rotation and translation invariant
  - Matching Score > 40

↓

Finger Match


Template Minutiae Set
Fingerprint Minutiae Set
Construct Intra-Fingerprint Minutia Comparison Tables
Construct Inter-Fingerprint Compatibility Table
Traverse the Inter-Fingerprint Compatibility Table
Matching Score

Index

- Introduction
- Software Architecture
- **Hardware Architecture**
- Conclusions

Initial System Architecture

- Initi

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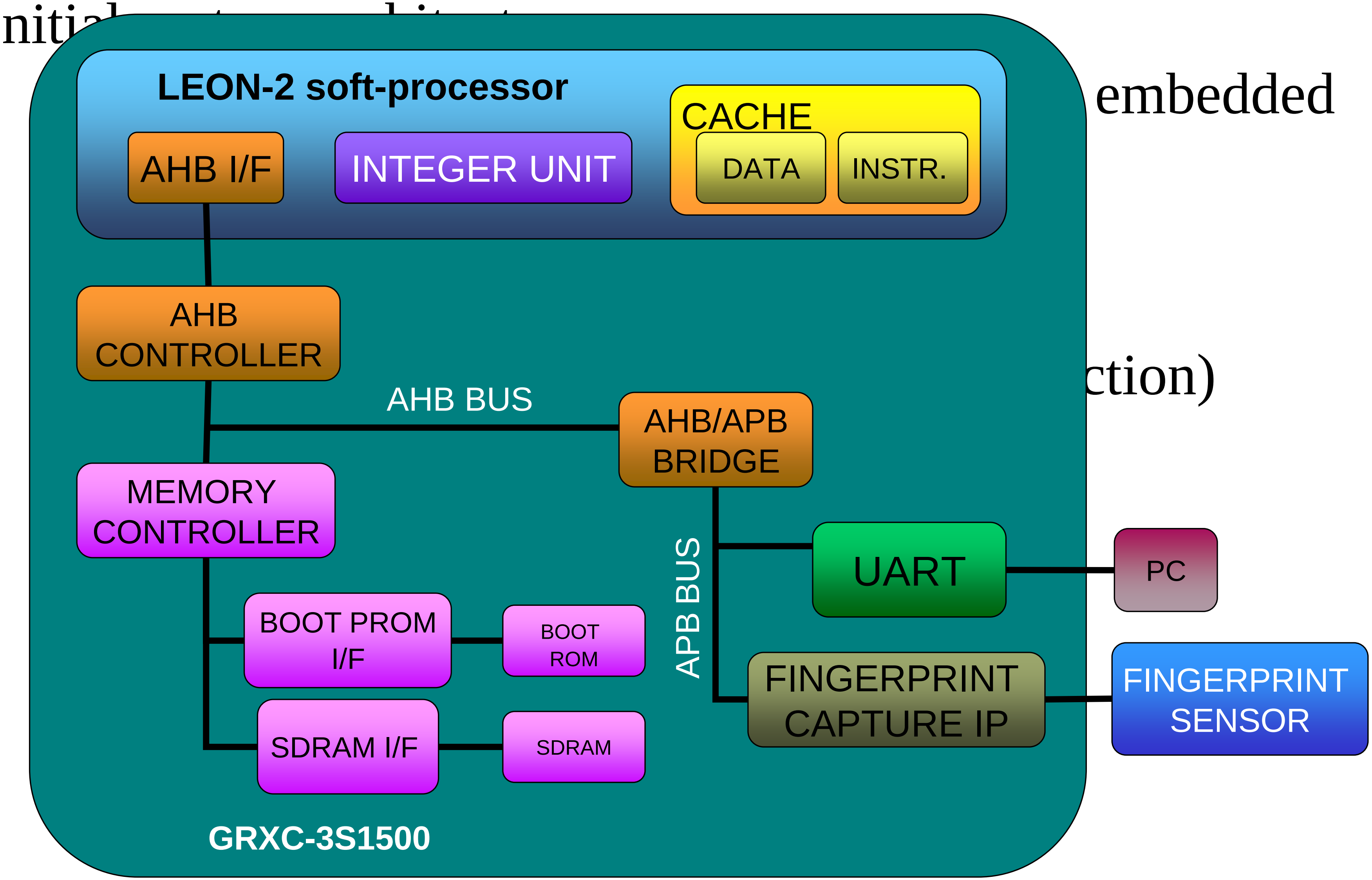


Initial System Architecture

- Why Leon2?
  - High configurability
    - VHDL code availability (under LGPL license).
  - High performance
    - Best performance per clock cycle
  - High usability
    - *Tkconfig* graphical configuration tool

Running the application on the initial system

- The execution of the algorithm is successful in terms of the matching results.
- Yet the execution time is excessive.
  - MINDTCT occupies 75% of the computation time.
- **MINDTCT acceleration**:
  - Mainly floating-point operations
  - Leon2 is a fixed-point processor

→ FPU

- Leon2 compatible FPUs:
  - LTH
  - Meiko
  - GRFPU

} IEEE-754 compliant

FPU tests

- FPU insertion → Great increase in the amount of logic
  - Reduce clock frequency
  - Reduce cache sizes
- Three different system configurations under test
  - 31 MHz and 8KB cache memory.
  - 37 MHz and 8KB cache memory.
  - 40 MHz and 4KB cache memory.

FPU tests

- Stanford benchmark
  - Measures the execution time in ms for ten small programs.

	A	B	C	D
Perm	34	50	33	34
Towers	50	83	67	50
Queens	33	50	33	33
Intmm	166	133	100	116
Mm	**1000**	**84**	**50**	**67**
Puzzle	317	450	350	350
Quick	50	50	33	33
Bubble	50	50	50	50
Tree	233	334	266	250
FFT	**1067**	**83**	**67**	**50**

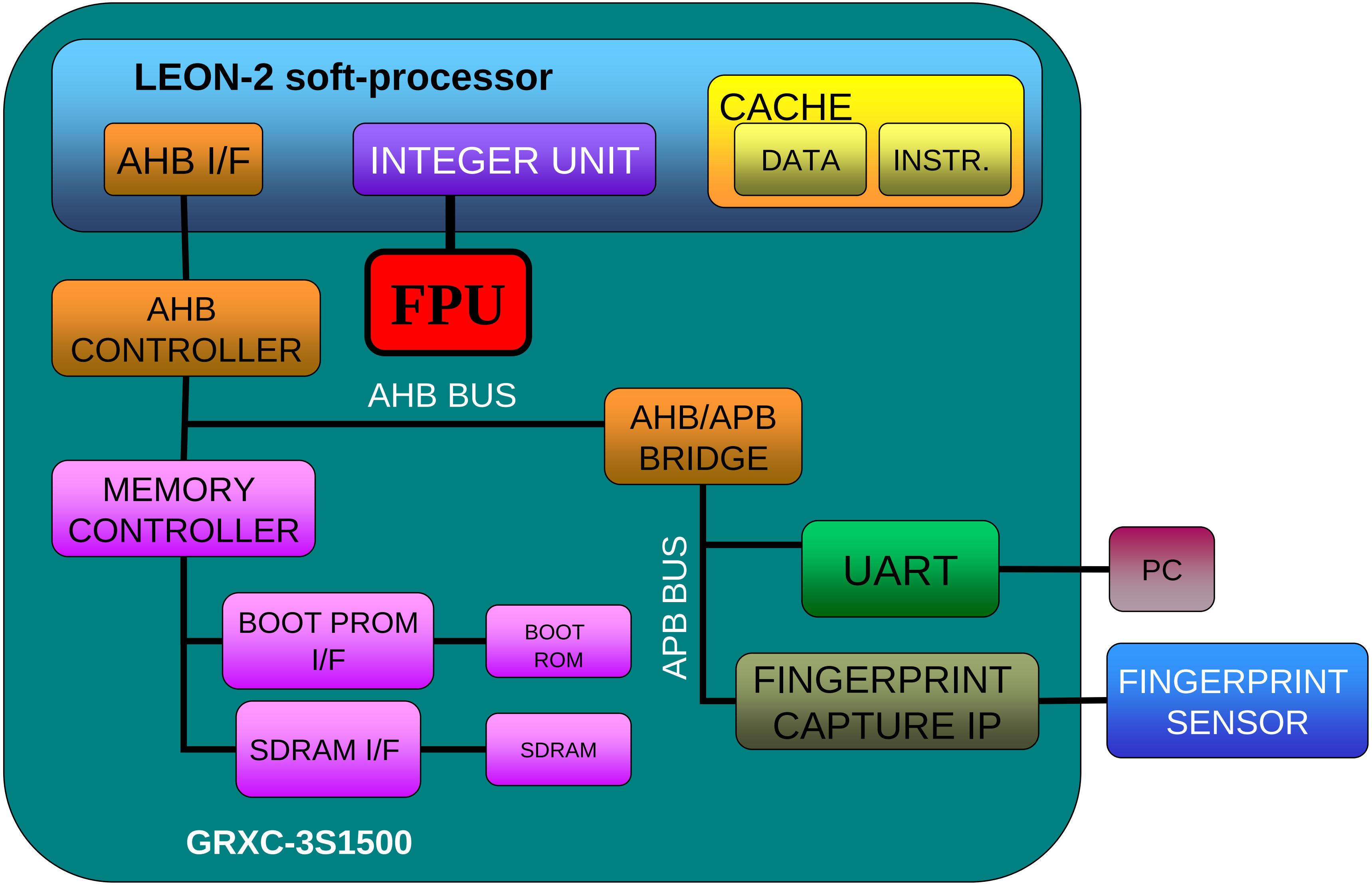
A: 50 MHz / 8KB cache /No FPU.
B: 31 MHz / 8KB cache / FPU.
C: 37 MHz / 8KB cache / FPU.
D: 40 MHz / 4KB cache / FPU.

→ 91.6% - 95% execution time reduction

→ 92.22% - 95.3% execution time reduction

- Paranoia benchmark
  - Test the compliance with the IEEE-754 floating-point standard

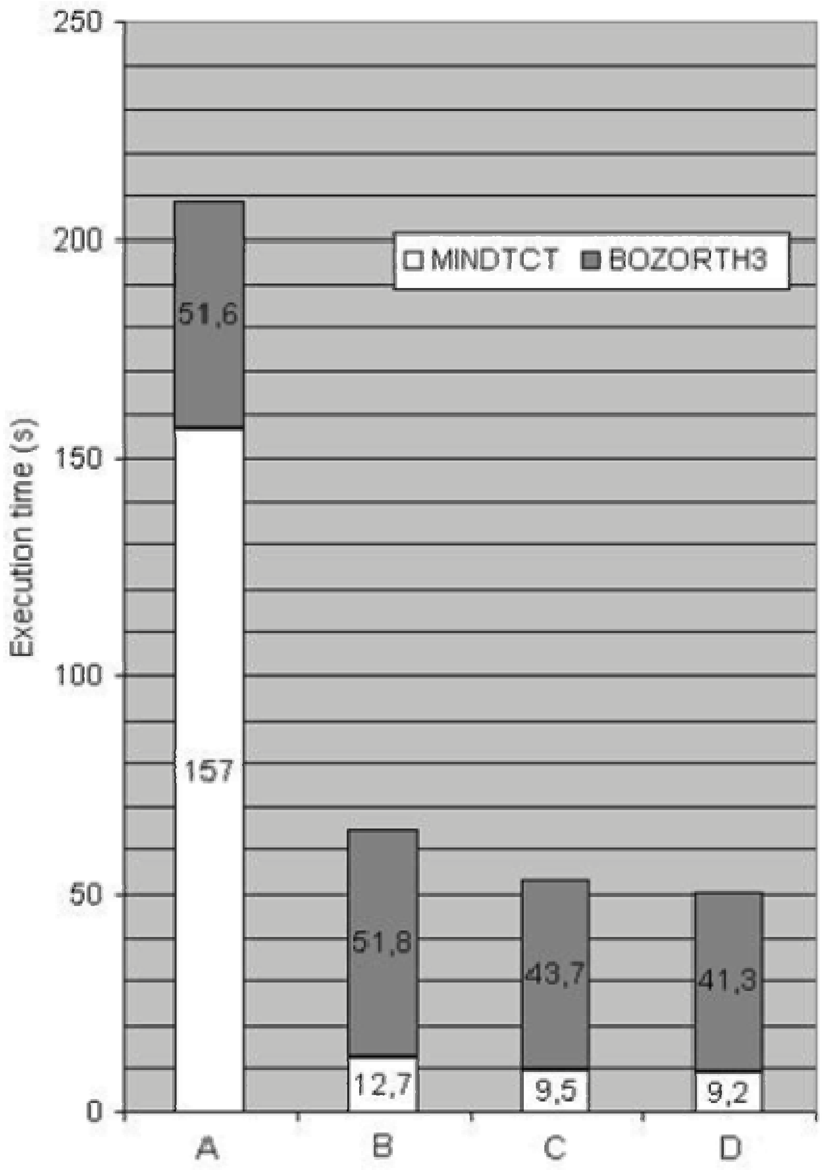
Introducing the GRFPU in the design



Introducing the GRFPU in the design

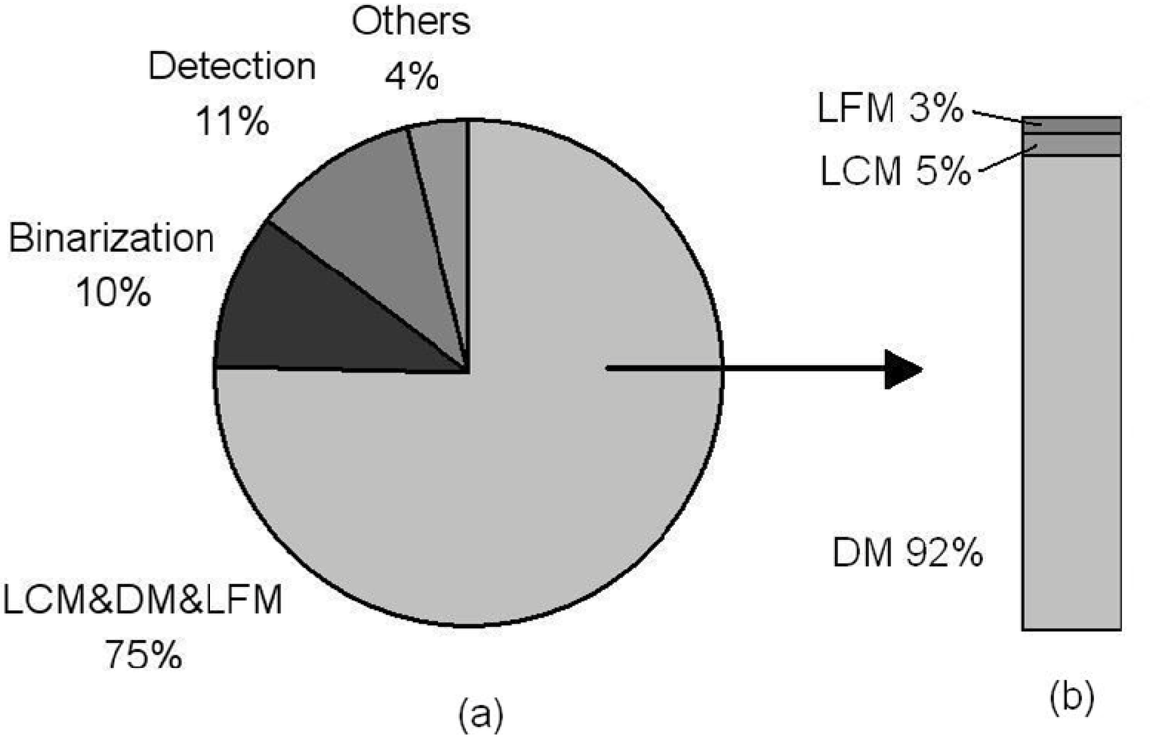
- 94.14% execution time reduction (40MHz / 4KB cache).
- Program completion delay is yet excessive.

A: 50 MHz / 8KB cache /No FPU / No HW Co-processor.
B: 31 MHz / 8KB cache / FPU / No HW Co-processor.
C: 37 MHz / 8KB cache / FPU / No HW Co-processor.
D: 40 MHz / 4KB cache / FPU / No HW Co-processor.



HW speed enhancement

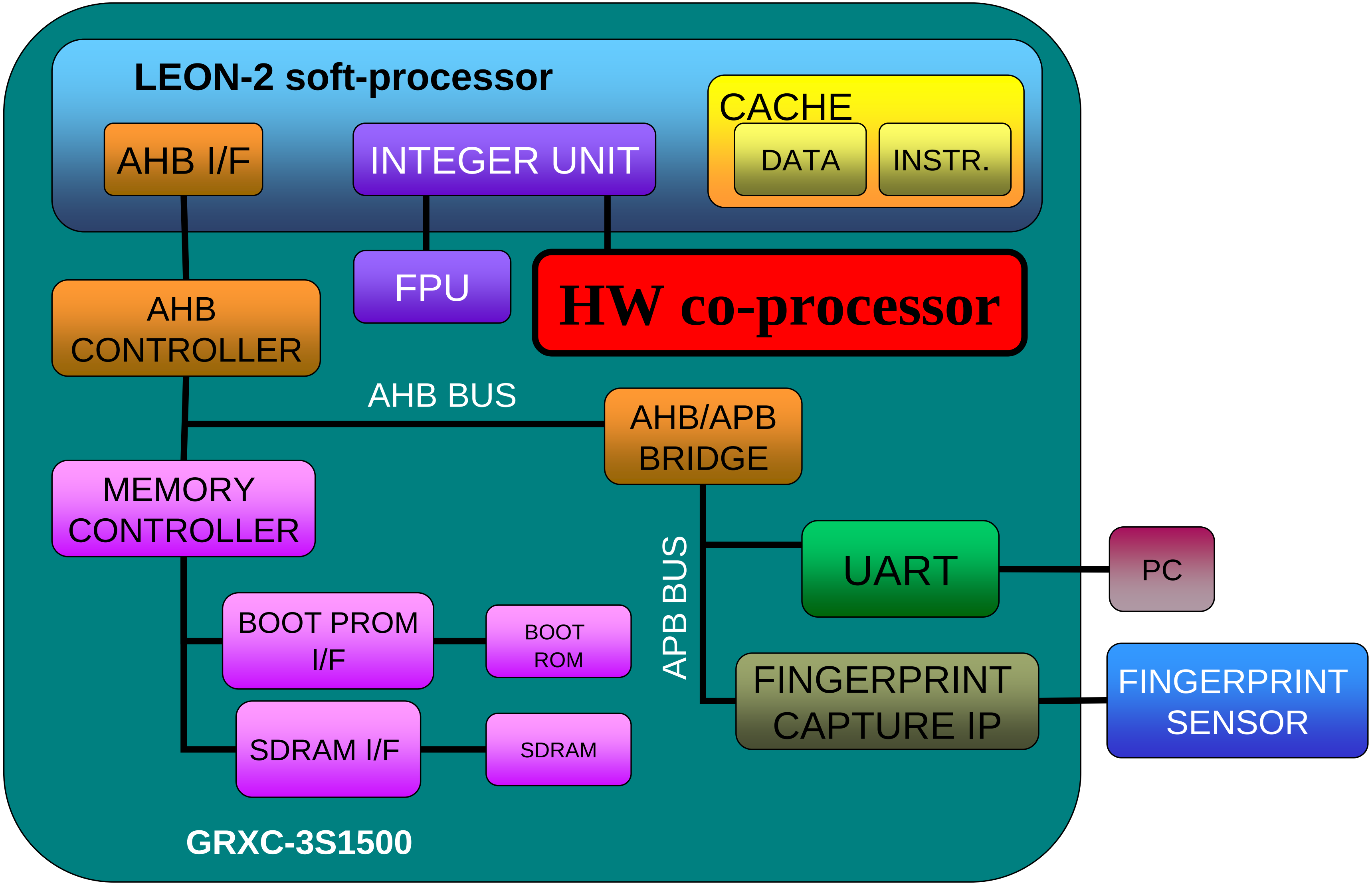
- MINDTCT completion time excessive ➡ Mainly due to DM.



LCM: Low Contrast Map.
DM: Direction Map.
LFM: Low Flow Map.

- HW accelerator speeds up this process

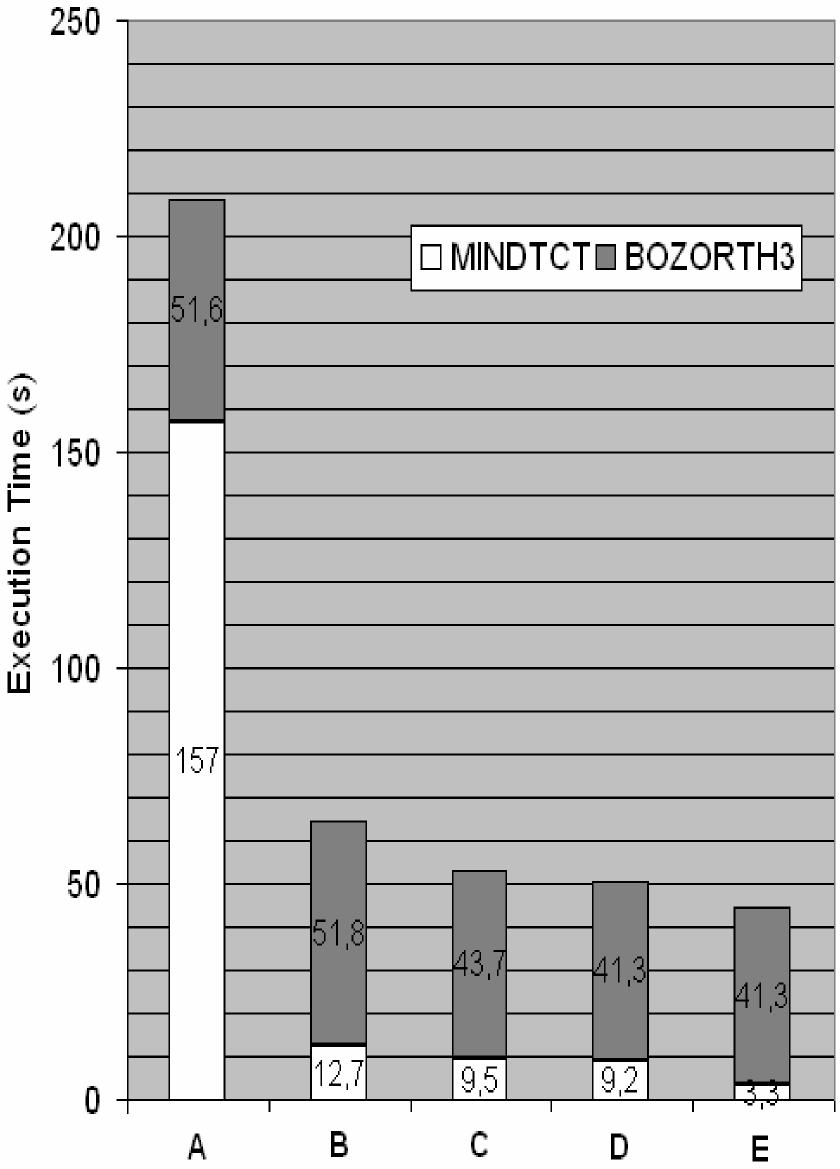
HW speed enhancement



HW speed enhancement

- 97.89% execution time reduction is estimated (40MHz / 4KB cache).

A: 50 MHz / 8KB cache /No FPU / No HW Co-processor.
B: 31 MHz / 8KB cache / FPU / No HW Co-processor.
C: 37 MHz / 8KB cache / FPU / No HW Co-processor.
D: 40 MHz / 4KB cache / FPU / No HW Co-processor.
E: 40 MHz / 4KB cache / FPU / HW Co-processor.



Index

- Introduction
- Software Architecture
- Hardware Architecture
- **Conclusions**

Conclusions

- Implementation of a fingerprint minutiae extraction and matching algorithm
    - Spartan3 based low-cost system
    - Embedded Leon2 soft-processor.
- Minutiae extraction process has been accelerated in a 94.14%.
- HW co-processor is estimated to speed-up the MINDTCT algorithm up to a 97.89%.
- Commercial systems use very high frequency clocks.
    - Extrapolating results (400MHz) → Minutiae extraction performed in 0’3 s.

Thanks for your assistance