May. 13th 2024

RAGE

Energy Consumption Prediction Framework in Model-based Development for Edge Devices

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Outline

- Background
- Proposed Method
- Evaluation
- Conclusion

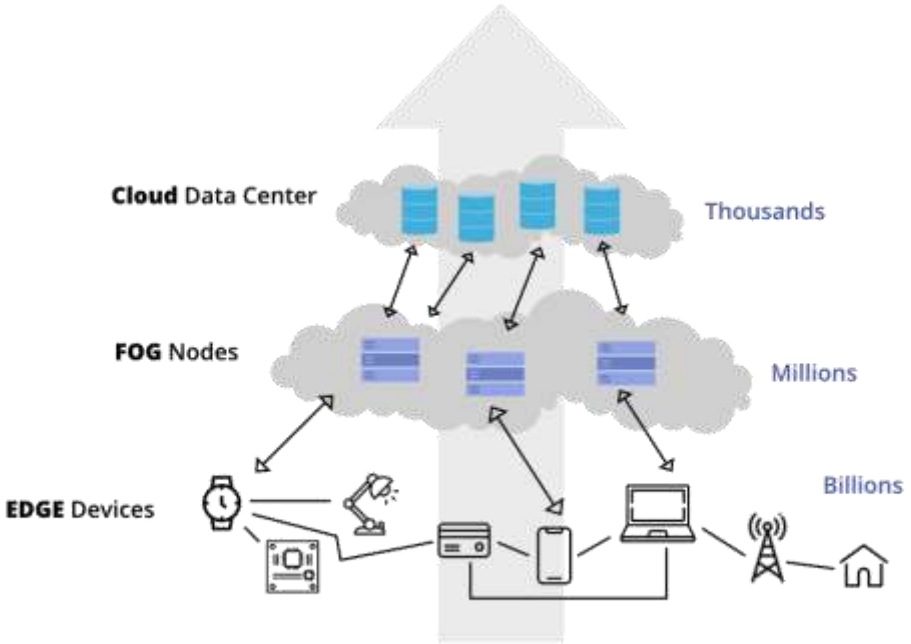
Edge Devices

■ Development of Edge Devices

- The count of devices is increasing
- Systems is becoming complex

■ Development of Systems on Edge Devices

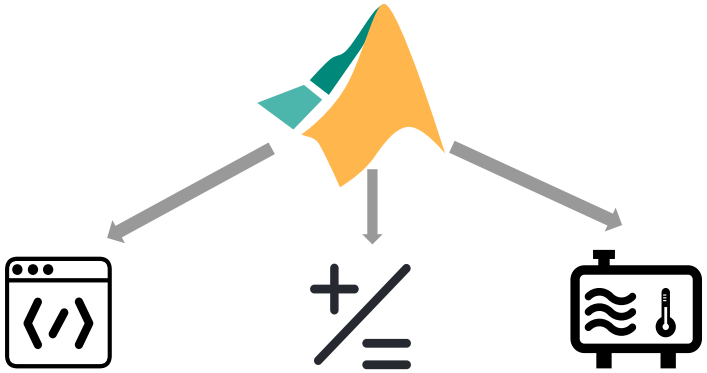
- The cost is becoming significant
- The reusability of the code developed with traditional method is limited



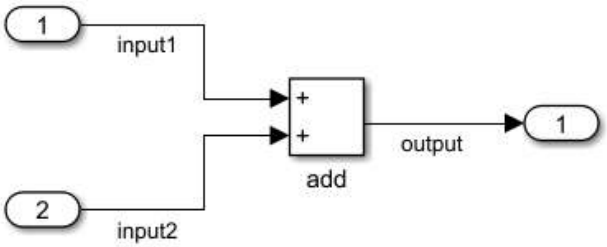
Model-based Development (MBD)

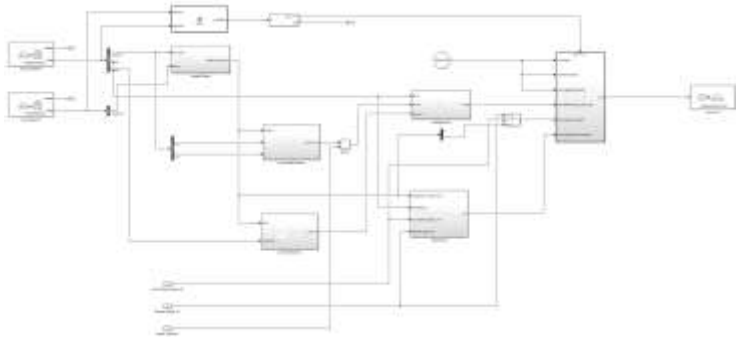
■ MATLAB/Simulink

- MATLAB: a programming and numeric computing platform developed by MathWorks



- Simulink: a block diagram environment for Model-based Development integrated with MATLAB

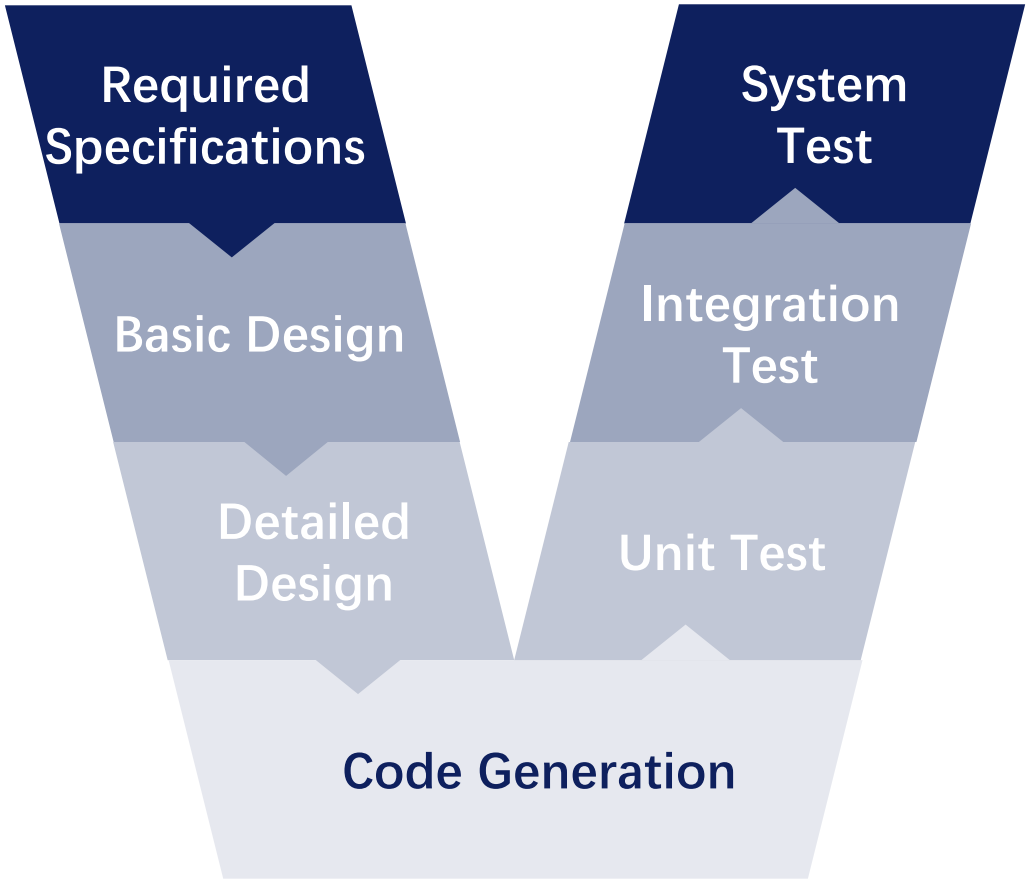




Model-based Development (MBD)

■ V-Model

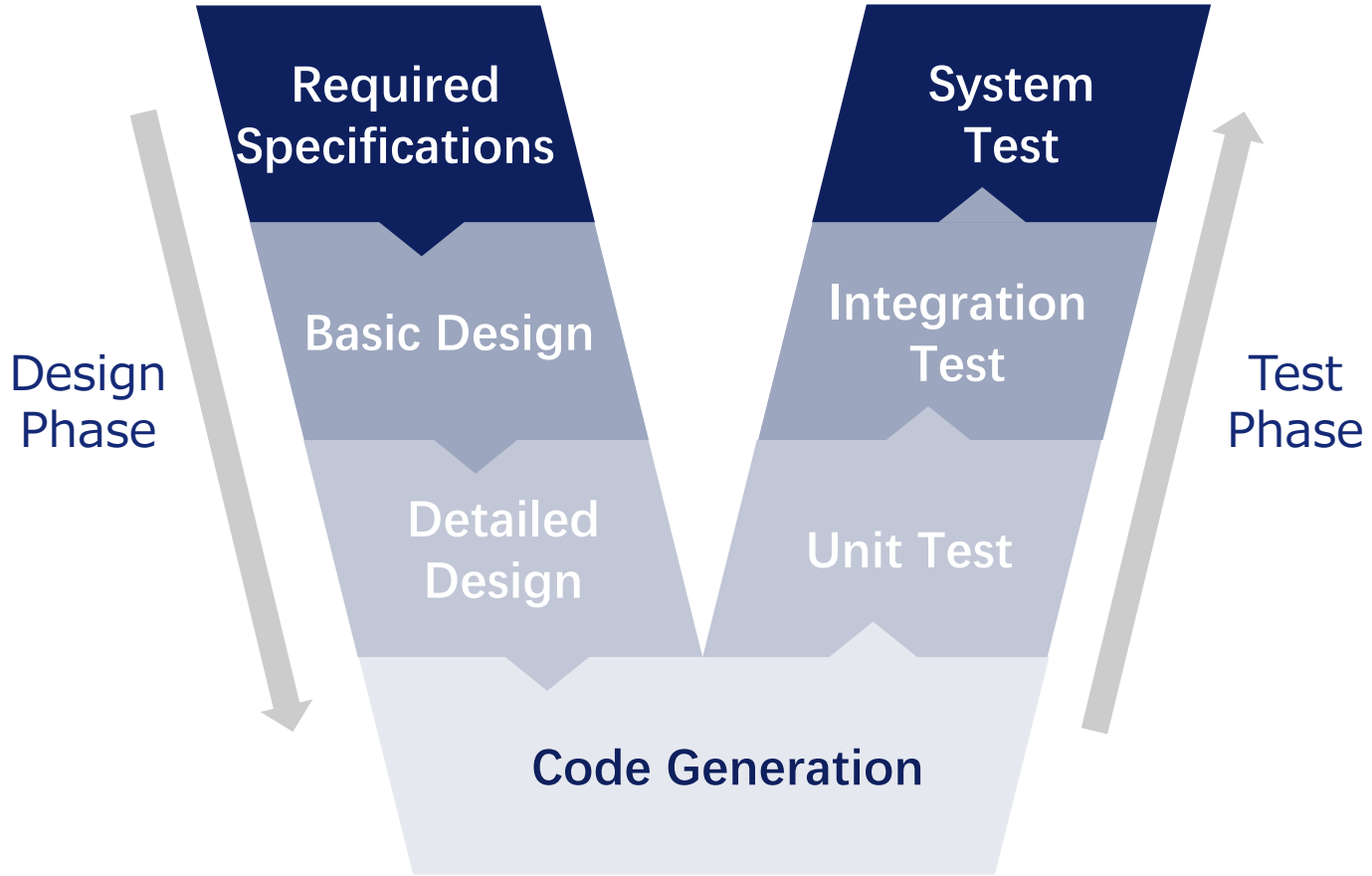
- A structured approach to system development that mirrors the stages of development with corresponding testing phases



Model-based Development (MBD)

■ Design Phase

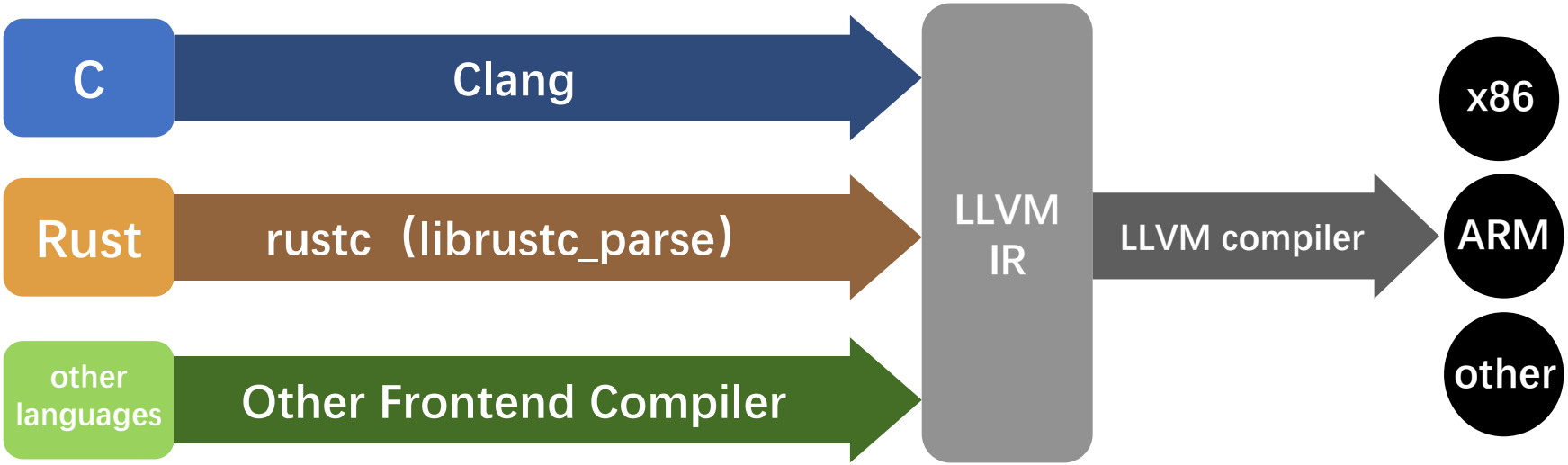
- Requirements Analysis
- Basic Design: simulation based on model (Energy is ignored)
- Detailed Design



Low Level Virtual Machine Intermediate Representation （LLVM-IR）

■ LLVM-IR

- A low-level programming language used as the primary IR within the LLVM compiler framework
- Serves as a bridge between high-level languages and the machine code, enabling code analysis and transformation



Contribution

[Contribution 1]
A schema is proposed to describe the energy consumption of instructions

[Contribution 2]
A method is proposed for extracting the working portion from generated code and transforming it into LLVM-IR

[Contribution 3]
A software tool is designed to predict model energy consumption

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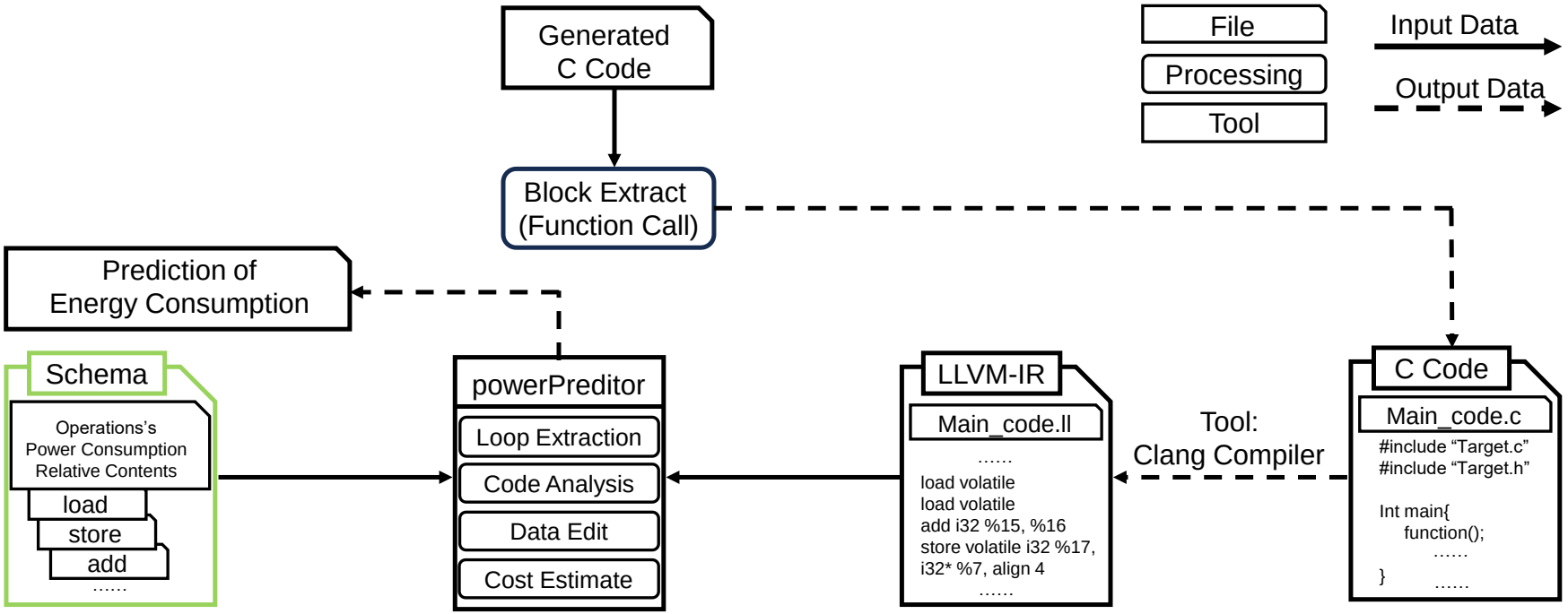
Energy Consumption Description Schema

■ Schema

- Provide a universal framework to describe energy consumption for any given instruction



[Proposed Method]

Energy Consumption Description Schema

■ Three-Tier Structure

- Top Layer
  - CommonInstructionSet
- Middle Layer
  - Instruction
- Bottom Layer
  - PowerConsumption

```
<CommonInstructionSet>
    <Instruction name="example">
        <PowerConsumption>
            <Cost>1.000</Cost>
            <Impact>0.000</Impact>
        </PowerConsumption>
    </Instruction>
</CommonInstructionSet>
```

Energy Consumption Description Schema

■ Acquisition Method

- Time and Energy
  - Execution time is directly linked to energy consumption
- Method
  - A cyclic execution approach is used for better precision in measuring individual instructions' time and energy use

Empty Body →

```
for (uint_t i = 0; i <= iteration; i++)
{
    asm volatile(”nop”)
}
```

Measured Body →

```
for (uint_t i = 0; i <= iteration; i++)
{
    asm volatile(”nop”)
    asm volatile(
            ”ADD %0, %1, %2\n\t”
            :”=r”(r6)
            :”r”(r4), ”r”(r5));
}
```

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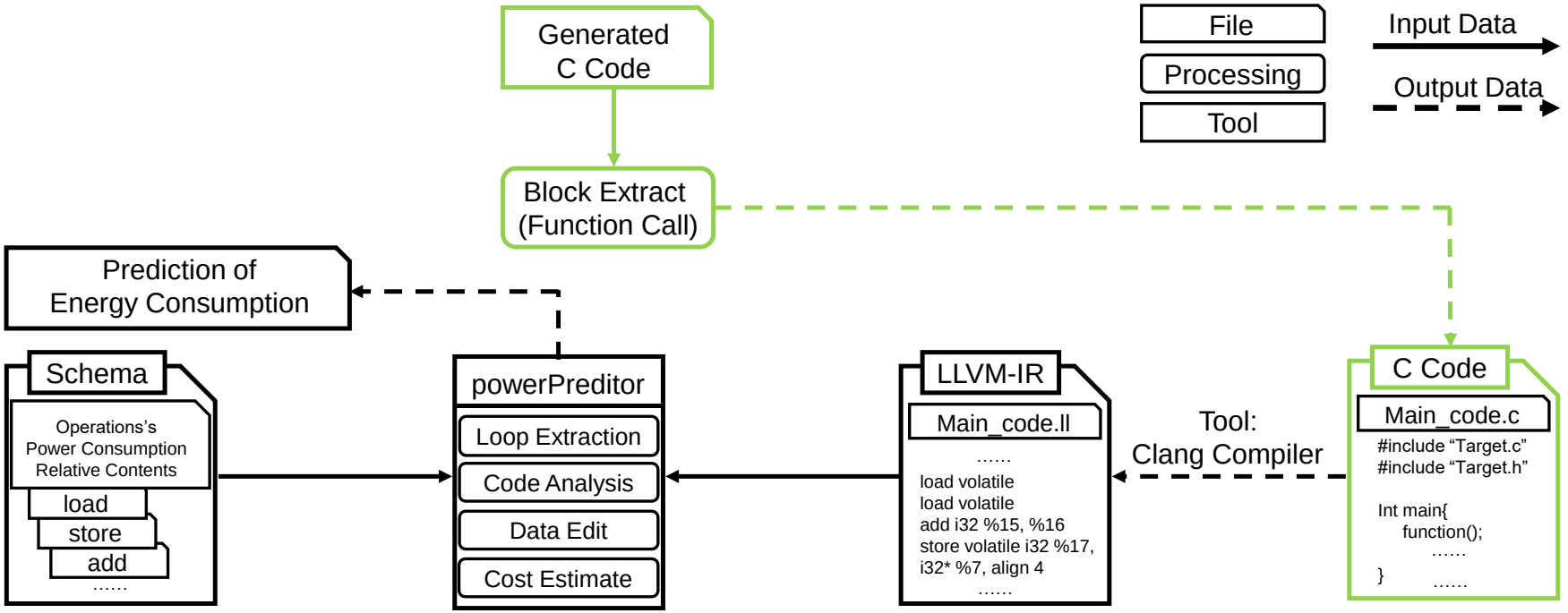
Extracting Working Portion

■ Function Call

- Call the main function section in the generated file by means of a function call in the new c-file



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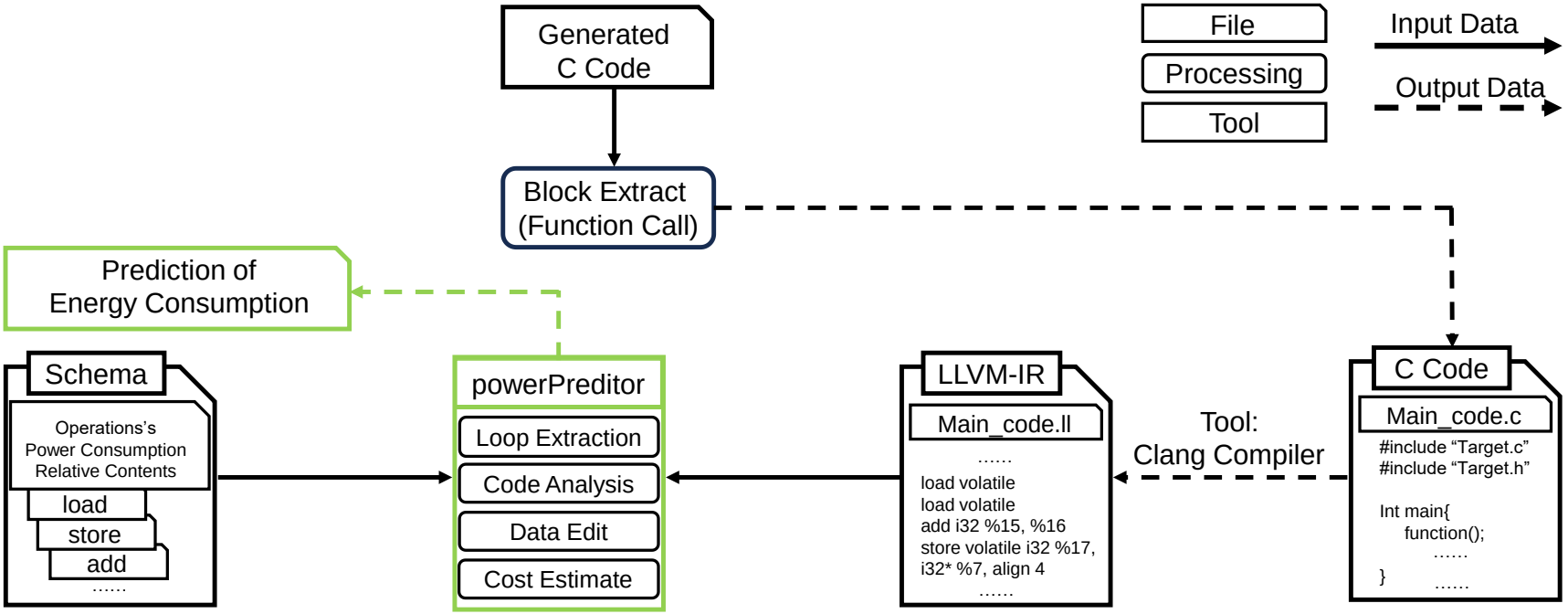
Prediction Tool

Input

- Schema
- LLVM-IR Code

Output

- Prediction of code's energy consumption



Comparison with Other Methods

	Modeling	Code Generation	Energy Consumption Measurement	Energy Consumption Prediction
MDD [7]	○	○		
Mercury [8]	○	○		
IEEE Access [9]			○	
SDK4ED [10]			○	○
J4CS [11]			○	○
PARTSim [12]			○	○
This Paper	○	○	○	○

Other approaches either focus purely on MBD or on code energy consumption prediction

Our research fuses the prediction process into mbd, enabling code energy prediction at the primary stage of development

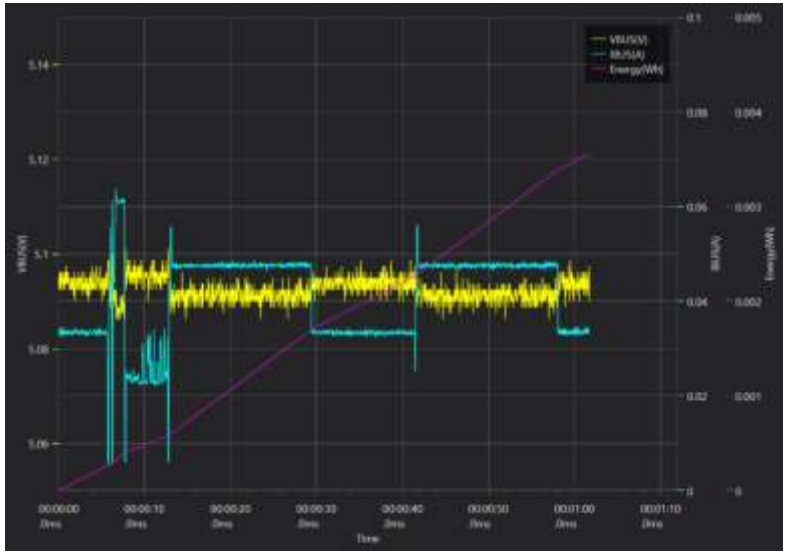
Experimental Environment

■Target device

- SONY Spresense (ARM Cortex M4F)

■Measurement device

- AVHzY CT-3 USB tester

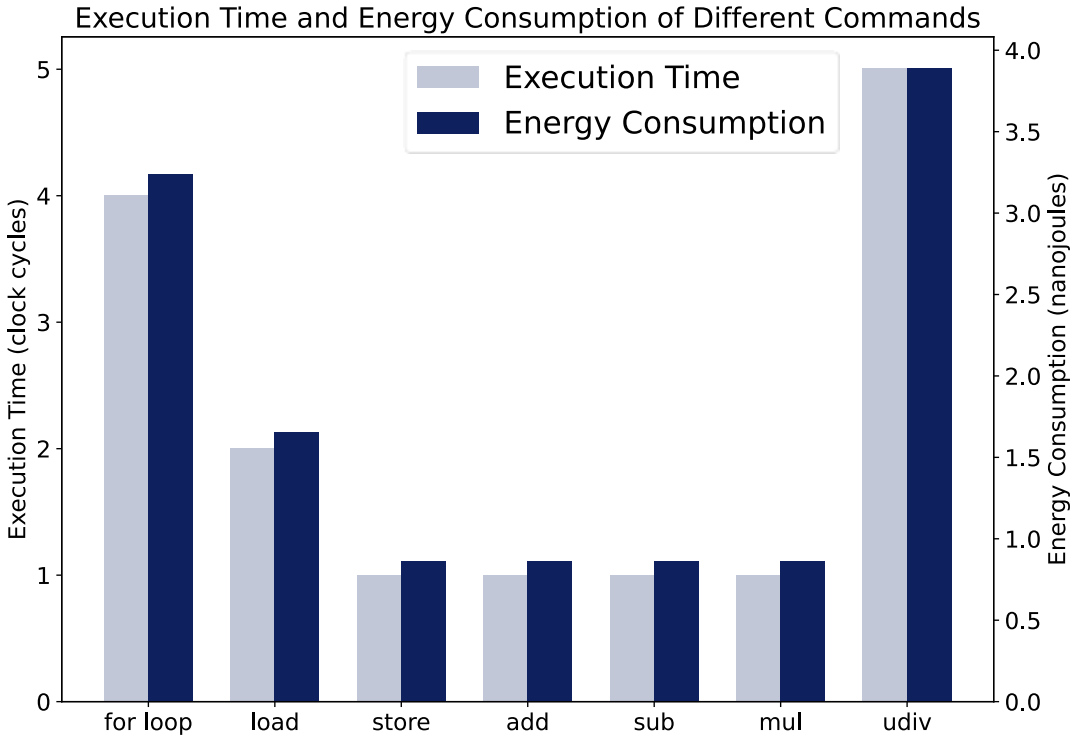


Experimental

■Basic Evaluation

- Measure the power consumption and execution time of basic instructions on the target device

- Create test scripts to obtain actual execution time and power consumption in a single core environment

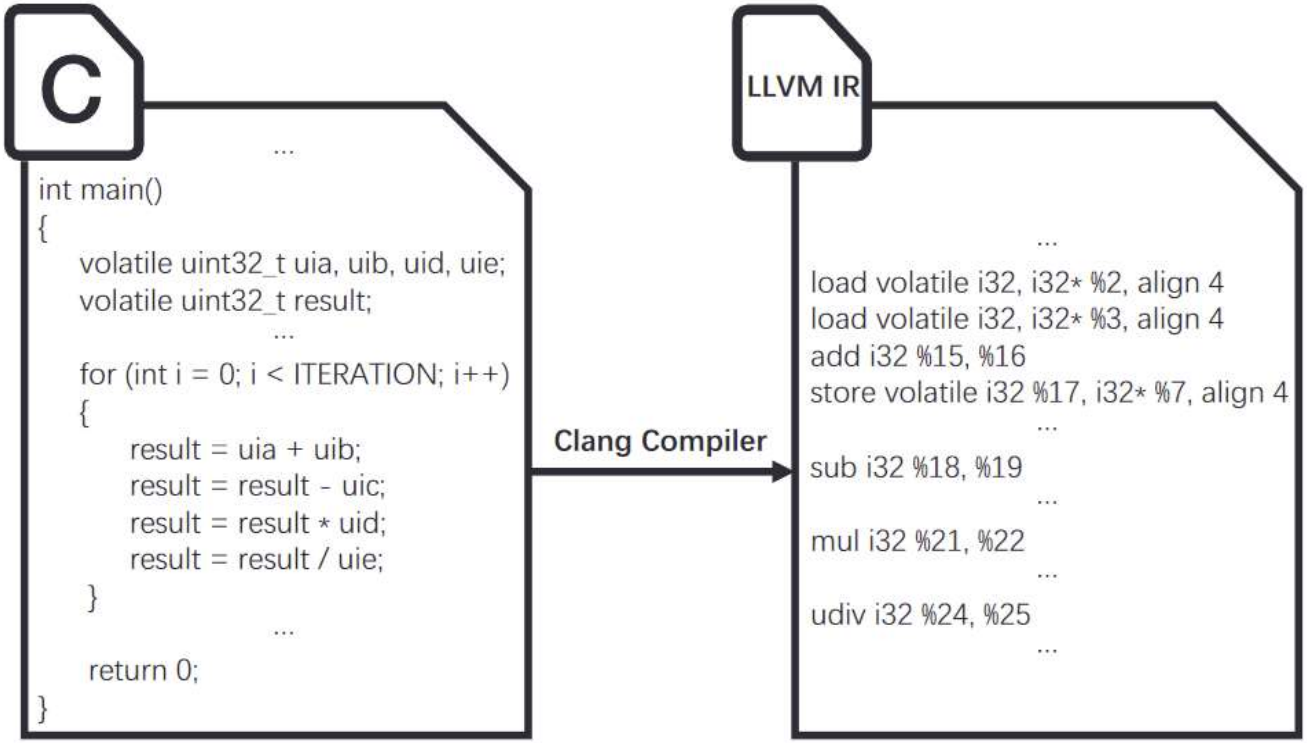


Experimental

■Basic Evaluation

- Test Scripts
  - Four arithmetic operations（add,sub,mul, and div)

- Predicting power consumption
  - Focus on the “for” statement part



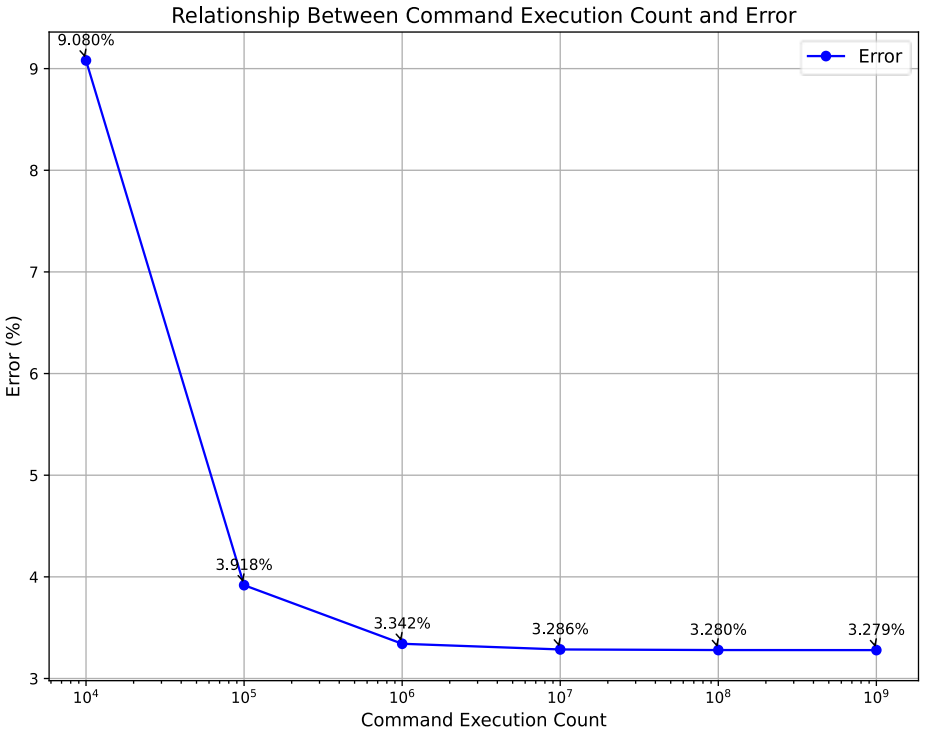
Test Scripts

Experimental

■Basic Evaluation

	Number of Execution	Total Time (clock cycles)	Total Energy (nanojoules)
load	**8**	**16.018**	**13.248**
store	**4**	**4.005**	**3.456**
add	1	**1.001**	**0.864**
sub	1	**1.001**	**0.864**
mul	1	**1.001**	**0.864**
udiv	1	**5.006**	**3.888**
for	1	**4.007**	**3.24**
Total		**32.039**	**26.424**

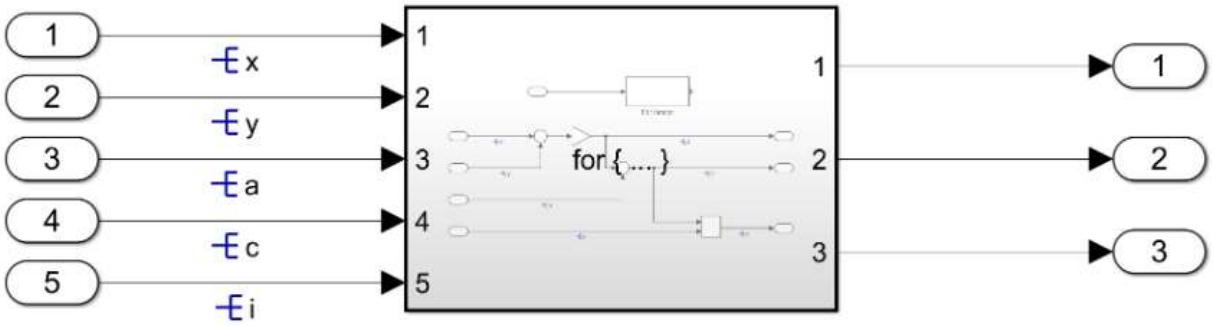
Time and Energy Consumption of Instructions



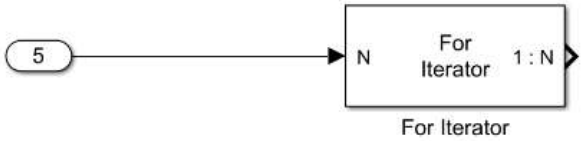
Power Consumption Prediction Focus on “for”

Experimental

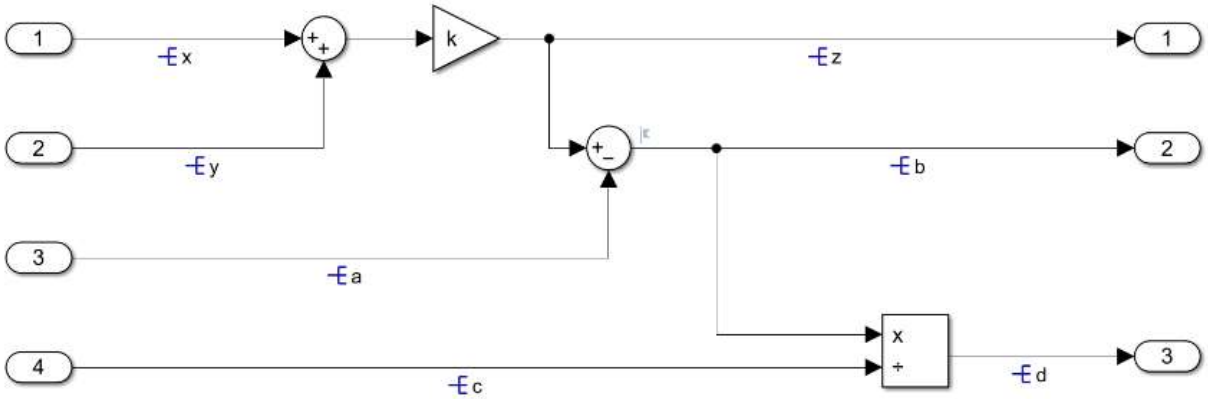
■Evaluation with Models



Overall Model Construction



For Iterator



For Iterator Subsystem Construction

Experimental Environment

■Evaluation with Models

- Code generated by Embedded Coder
- Execute in user code with function calls
- Convert to LLVM-IR instructions
- Make predictions with proposed tool

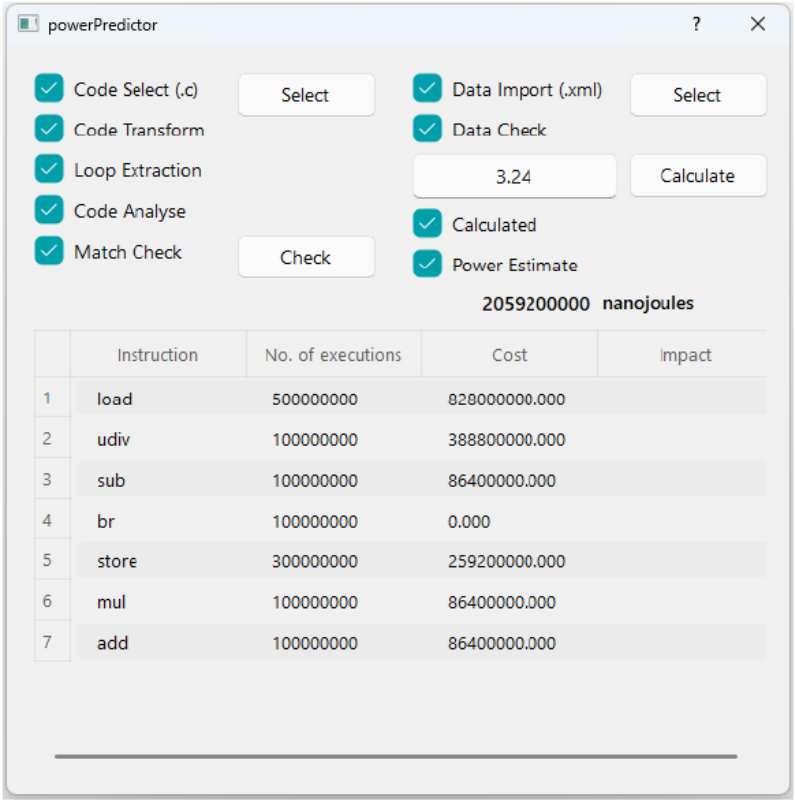
```
for (si_iter = 1; si_iter <= temp; si_iter ++)
{
    z = ( x + y) * k;
    b = z - a;
    d = b / c;
}
```

Experimental Environment

■Evaluation with Models

- Result
  - Prediction
    - 2,059,200,000 nJ
  - Measurement
    - 1,980,000,000 nJ
  - Error: 4%

- Error Analysis
  - Focus on “for” statement
    - Other codes’ ignored
  - Precision of the equipment
    - 1,000 times per second



Conclusions

Proposed Method

- Schema Construction: a structured approach to modeling energy consumption
- Module Extraction: parts of the model relevant to energy consumption
- Energy Consumption Prediction Tool: software to predict energy consumption

Contribution

- Provide a robust method for estimating energy requirements in embedded systems

Evaluaion

- Validate the availability of schema through basic evaluation
- The usability of the method in Model-based Development is verified by means of actual model