Towards Dynamically Composed Real-Time Systems

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Agenda

- Introduction
- Software Generation
- Update Mechanisms
- Real-Time Awareness

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Real-Time Systems

Real-time systems operate on time constraints.
Reaction to events or inputs must occur within a defined time window – not too late, not too soon.

Failure on keeping the time requirements might result in:

- Heavy damages in **hard real-time** systems
- Undesirable, but tolerable problems in **soft real-time** systems

Dynamically Composed Systems

- Modular systems
- Partial updates
- On-the-fly updates

Dynamically Composed Real-Time Systems

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- Partial updates
- On-the-fly updates

- System remains real-time at any point in time: before, during and after any upadtes.

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Multi-Core Sustainable modular adept real-time Operating System

Motivation

- Internet of Things (IoT) → Billions of devices
- More software customization → Software diversity
- More software providers → Access restrictions
- More classes of systems → Common processor and services

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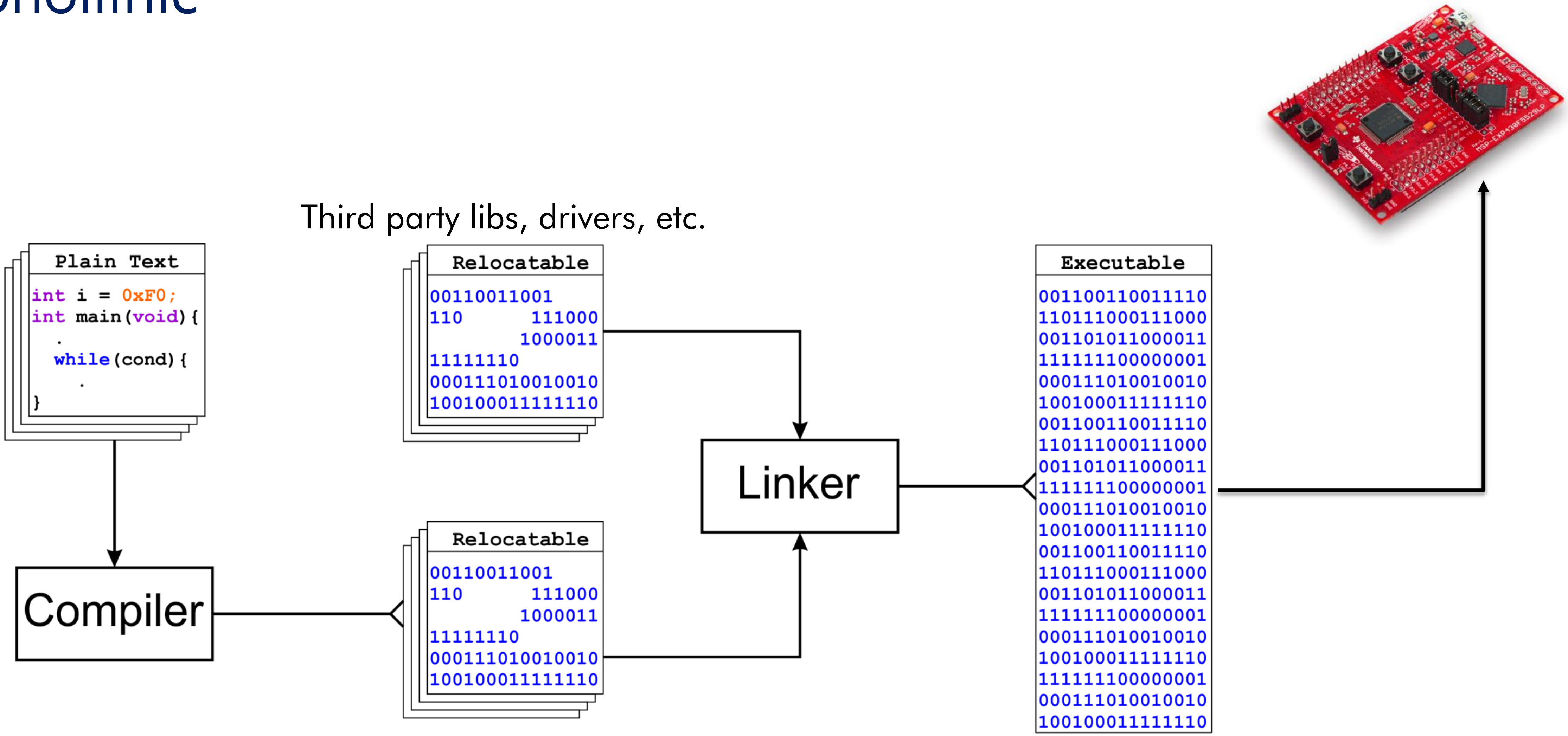
Monolithic



Third party libs, drivers, etc.
Plain Text
int i = 0xF0;
int main(void){
while(cond){
}
Compiler
Relocatable
00110011001
110 111000
1000011
11111110
000111010010010
100100011111110
Relocatable
00110011001
110 111000
1000011
11111110
000111010010010
100100011111110
Linker
Executable
001100110011110
110111000111000
001101011000011
111111100000001
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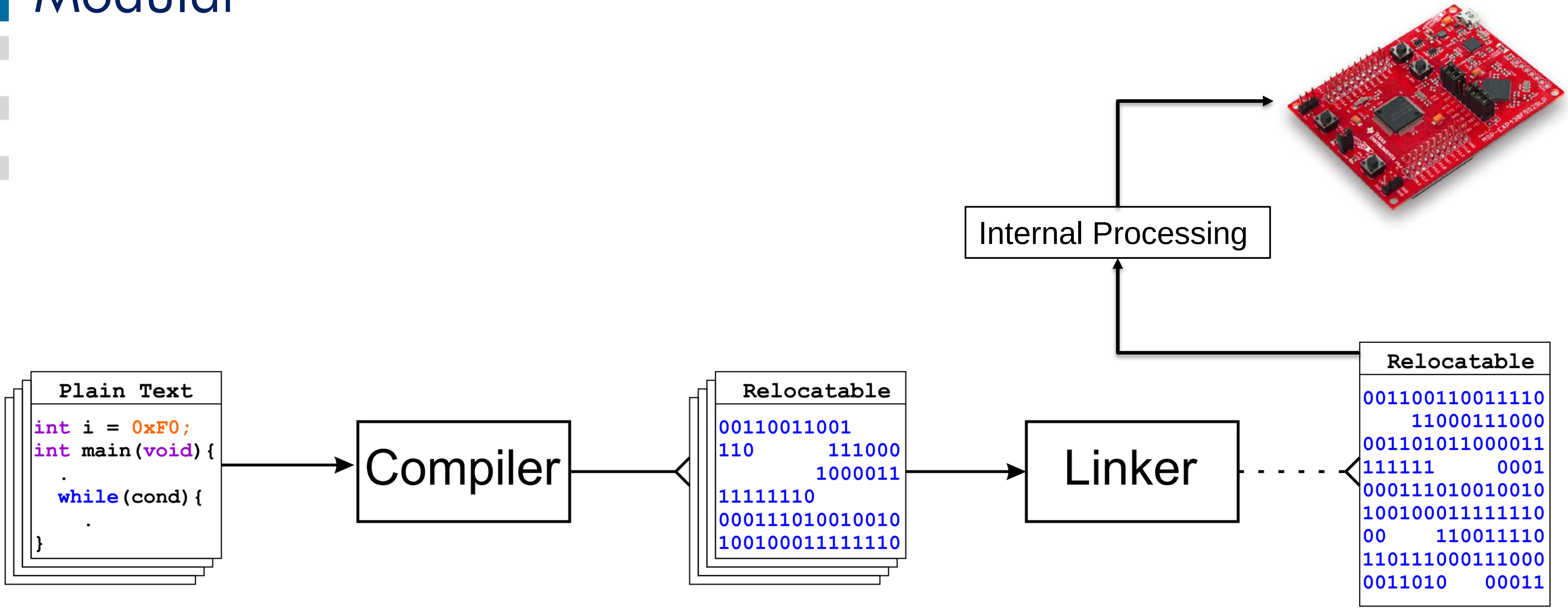
Modular



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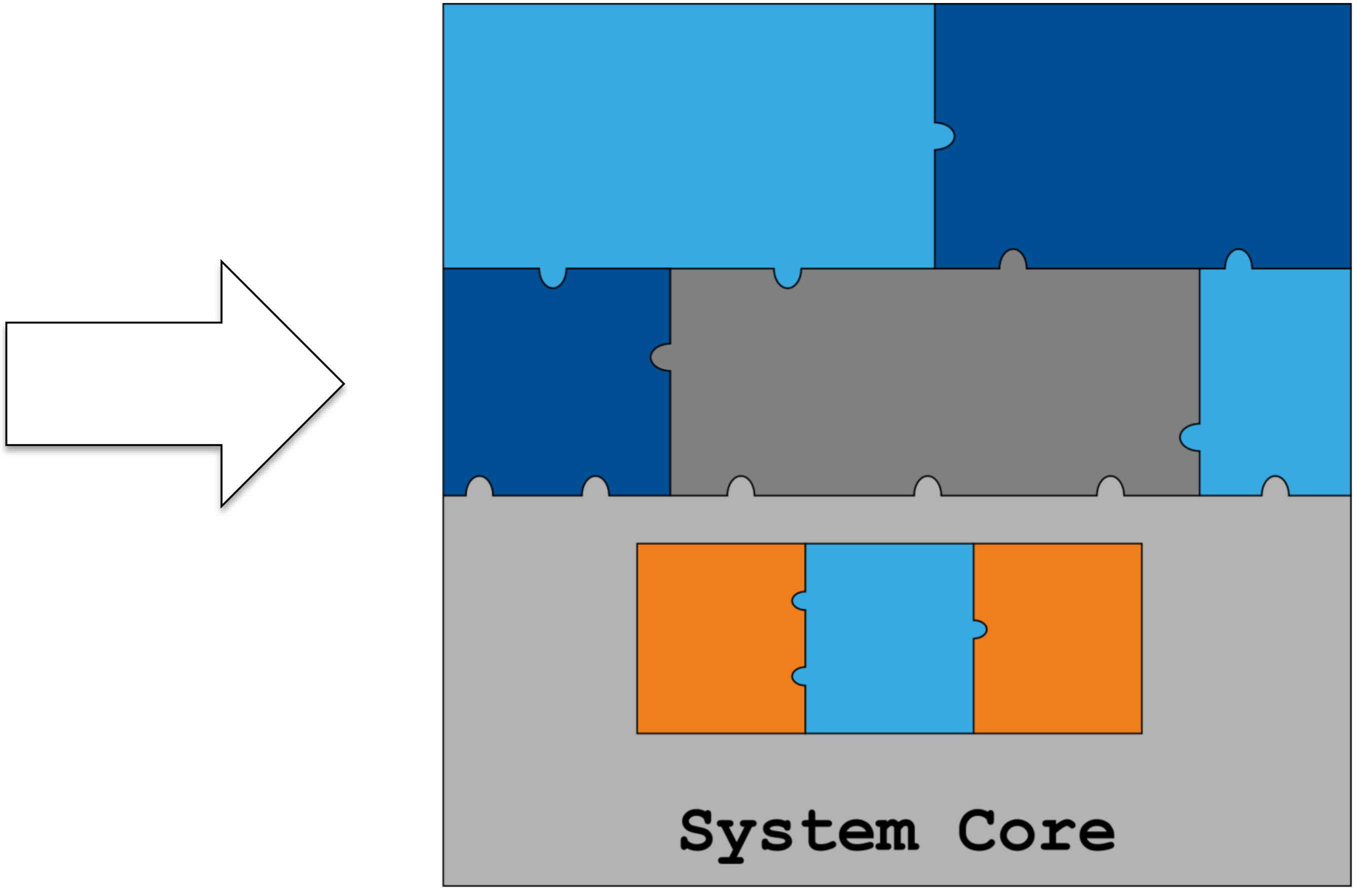
Internal Processing

Modular Executable



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Why update?

- Bugfixes
- Security breaches
- New requirements/legislation
- Enhancements
- Reconfigurable hardware

How to update?

- Physical access

Normal Operation Disrupted?

- Remote updates
  - User awareness
  - Background updates

Our Focus

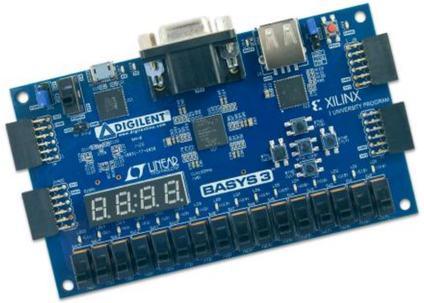
- Physical access

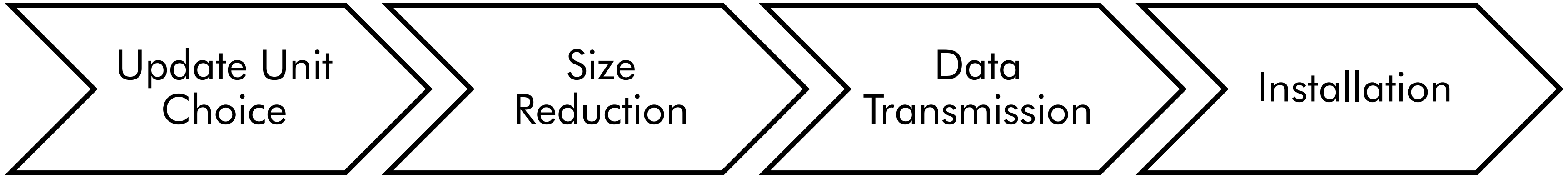
Normal Operation Disrupted?

No!

- Remote updates
  - User awareness
  - Background updates

General Steps





- Monolithic
- Native Module
- VM Module

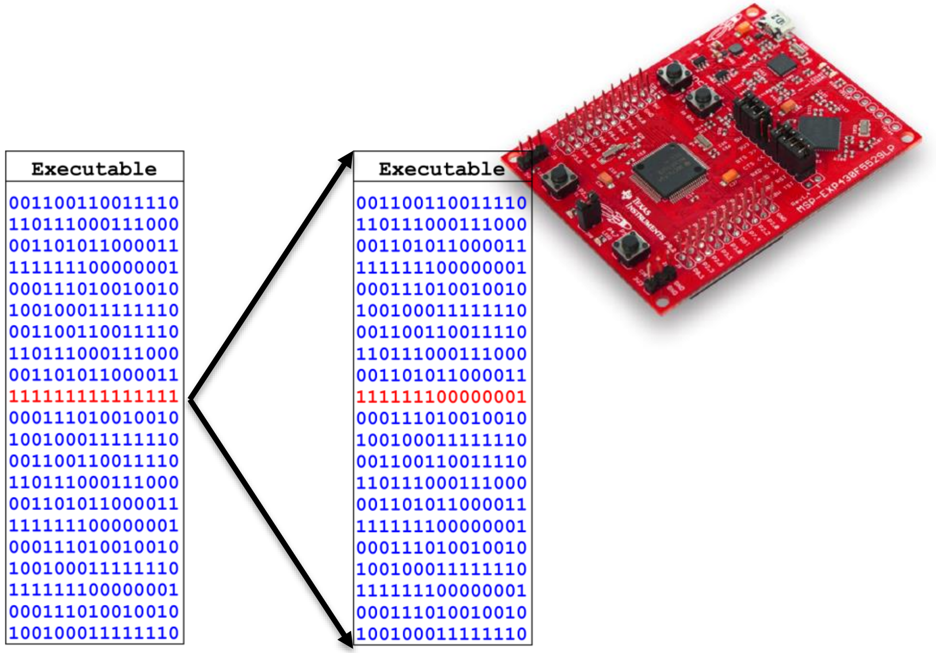
- ELF Optimizations
- Delta Files
- Compression

- Server-Client
- Dissemination Protocols

- Authenticity
- System Configuration
- Linking/Relocation
- Load and Execution

Update Unit – Monolithic

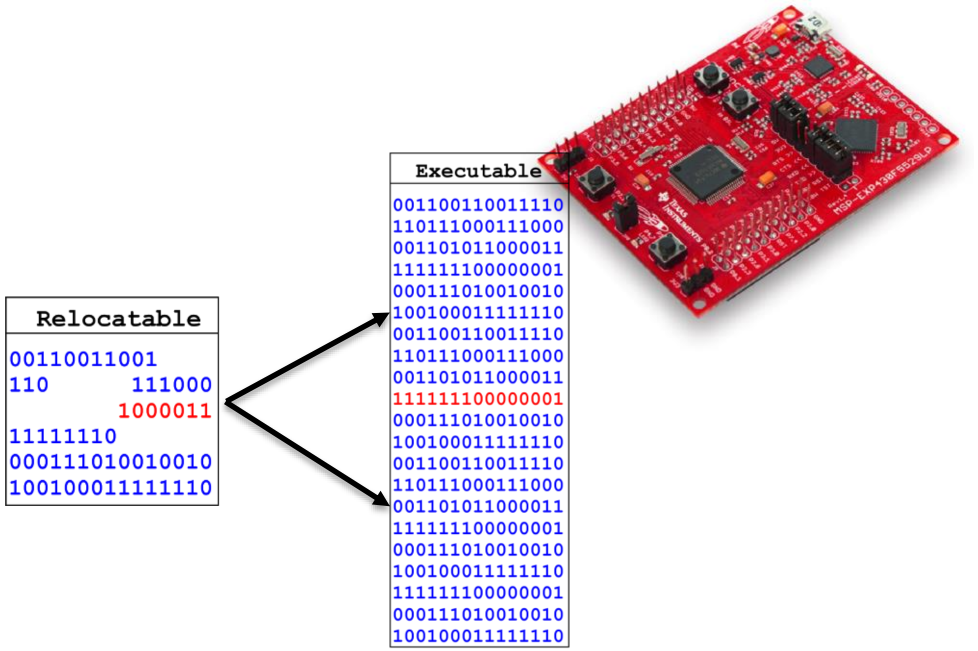
- Example: TinyOS



Update Unit – Native Modules

- Relocatable Code Only
  - Example: Contiki
  - 45%-55% metadata overhead [1]
  - ~13% faster than PIC [2]

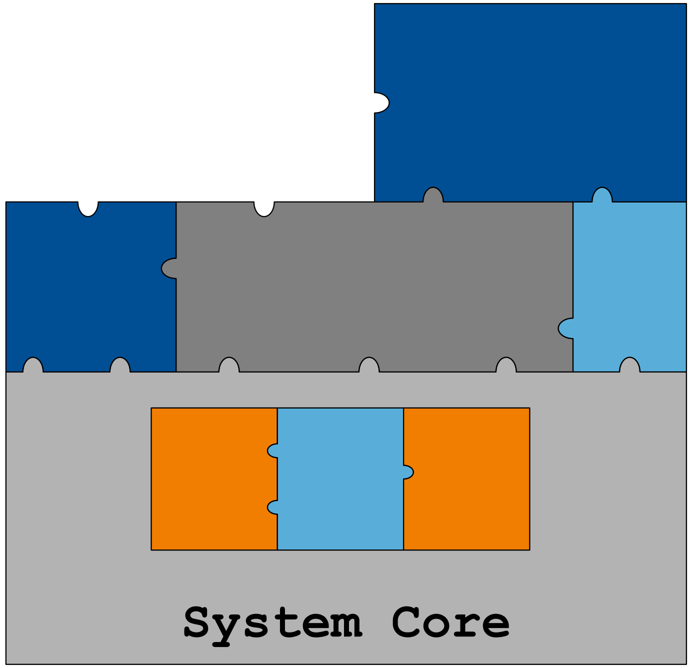
- Position Independent Code (PIC)
  - Example: SOS
  - Less metadata overhead
  - Compiler and architecture dependent



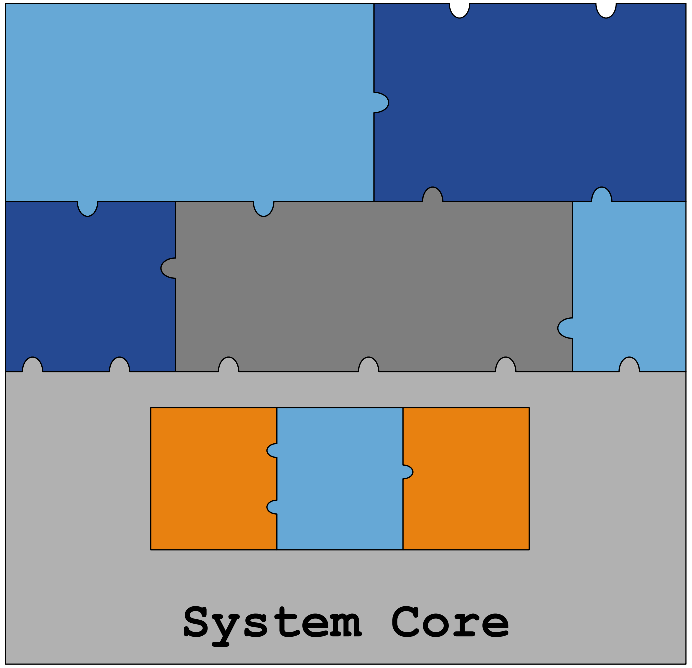
Update Unit – Native Modules

Potential Problems

- Removal of a module needed by other modules



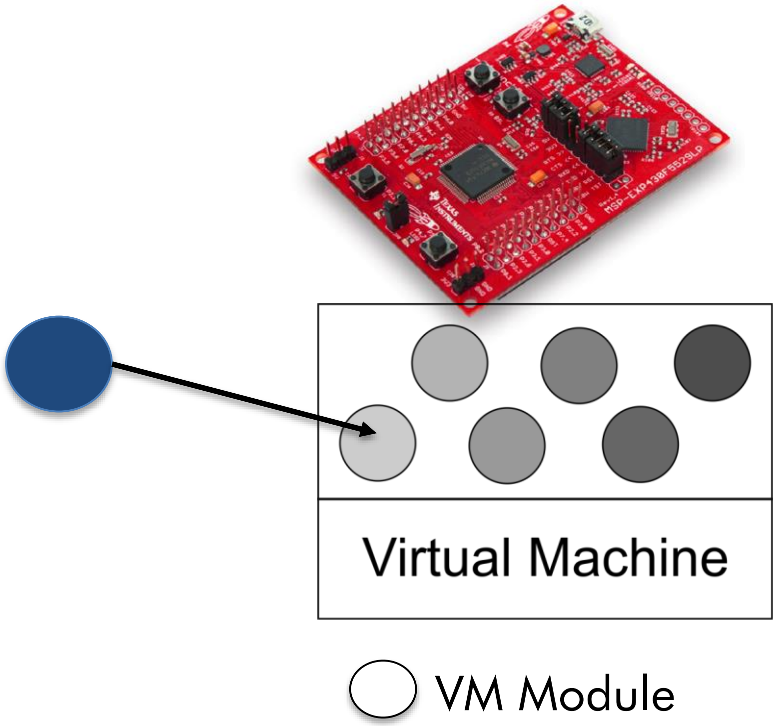
- Dependencies not present in current system



Update Unit – VM Module

VM execution overhead

- processing overhead due to code interpretation at runtime mostly outweighs the costs saved in the transmission [3]



Size Reduction

ELF Optimization

- CELF [3]
  - Fields size reduction 32/64 bits → 8/16 bits
  - CELF → typically ~ 50% of ELF

- SELF [4]
  - Fields size reduction
  - Tailoring of relocation, string and symbol tables
  - SELF → 15%-30% of ELF | 38%-83% of CELF
  - Loading speed 40%-50% of standard mechanism

Size Reduction

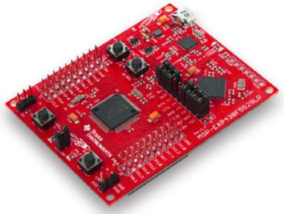
Delta Files

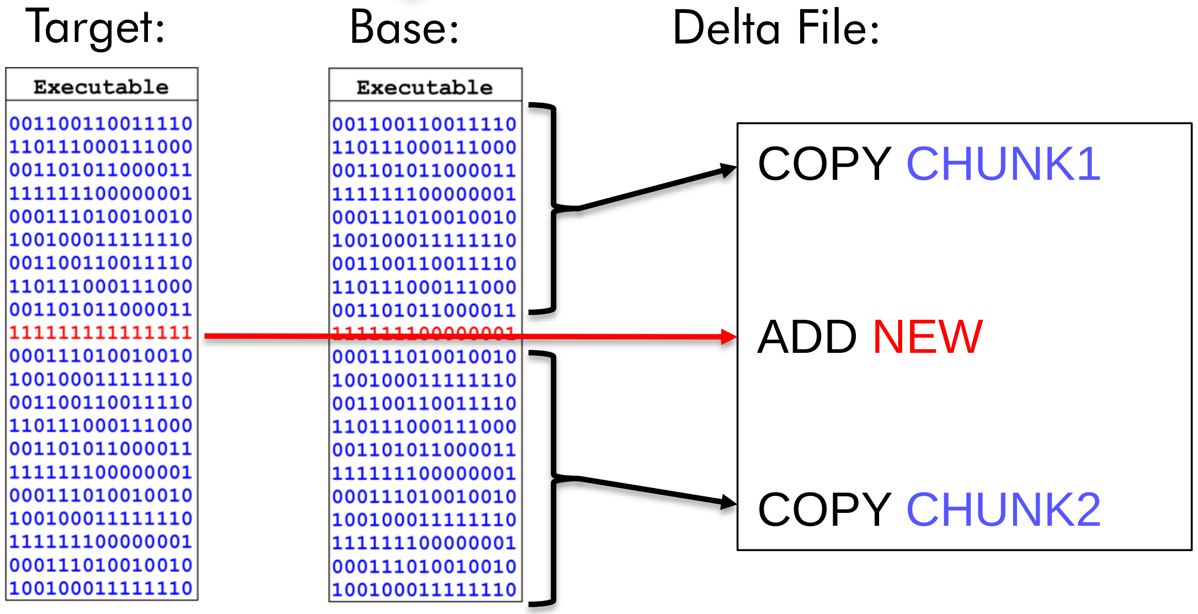
Incremental Approach

- Target version built on server
- Delta file generated on server
- Delta file transmitted
- Target version rebuilt on client

Techniques

- Slop regions[5]
- Similarity[6]





Size Reduction

Compression

- Decompression on client → More processing overhead
- Gzip on sensor nodes [7]

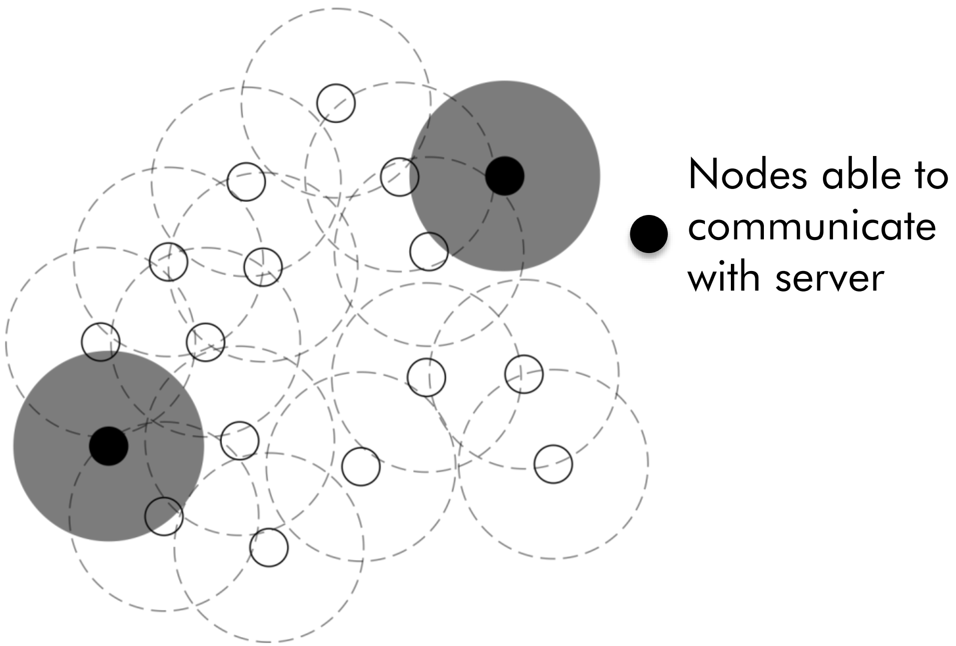
Data Transmission

Client - Server

- Point-to-point connection between server and target system

Dissemination Protocols

- Direct connection with some nodes
- Data distributed among remaining nodes



Installation

Authenticity Check

- Make sure updates are legit

System Configuration

- Check/resolve dependencies
- Set up control blocks (tasks, resources, etc)

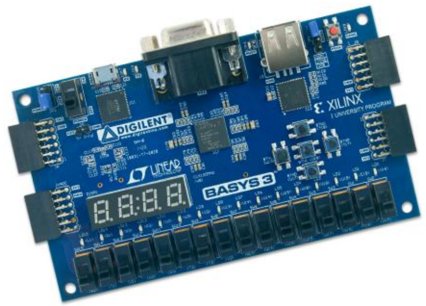
Linking/Relocation

- Transform a relocatable file in executable

Load/Execution

- Make software ready to run

Our Approach



Update Unit Choice → Size Reduction → Data Transmission → Installation

Update Unit Choice
- Monolithic
- Native Module
- VM Module

No PIC!

Size Reduction
- ELF Optimizations
- Delta Files
- Compression

Data Transmission
- Server-Client
- Dissemination Protocols

Installation
- Authenticity
- System Configuration
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- Load and Execution

+

Real-Time Awareness

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Current Approaches

Simple scenarios

- Rate-monotonic scheduling
- No resource sharing
- No task synchronization

Examples:

- *A model for updating real-time applications* [8]
  - New WCET $\leq$ Old WCET
  - New modules stored in the heap
- *A method for dynamic software updating in real-time systems* [9]
  - Schedulability analysis before accepting update
  - Update finishes within two hyper-periods

Our Goals

Offer partial on-the-fly updates and make sure the system remains real-time at any point in time: before, during and after any modification.

- Unintrusive updates
- Runtime schedulability analysis
- Minimize execution/memory overheads
- Loose coupling
- Portability / Use of standards
- Support wide range of devices

Trade-offs

Efficient analysis and low memory overhead

- Too little metadata → More modules, slow or impossible analysis
- Too much metadata → Less modules, faster or easier analysis

Low execution overhead and loose coupling

- Few Indirections → Low execution overhead, modules strongly coupled
- Many indirections → High execution overhead, modules loosely coupled

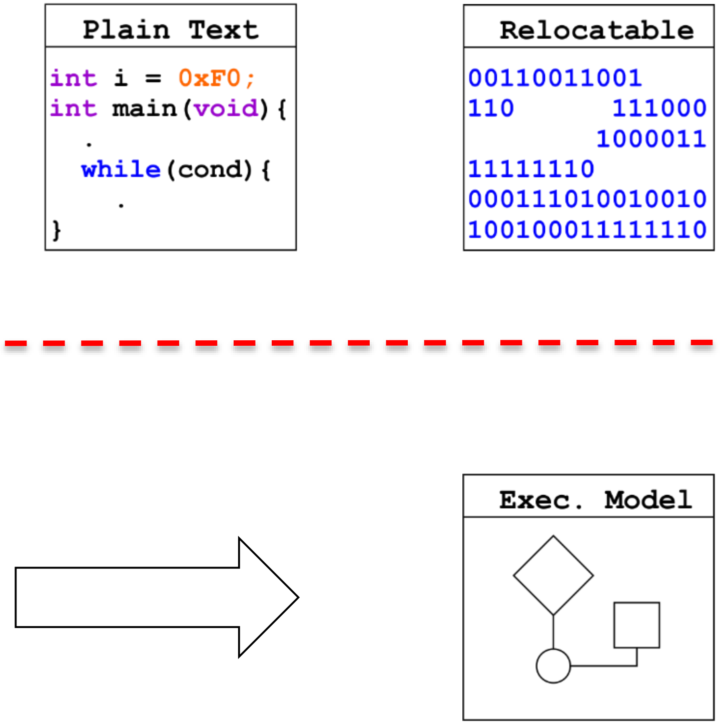
Generic updates and low client processing/memory overhead

- Server-only processing → Tailored updates, client simply loads the update
- Client-only processing → Generic updates, client analyzes and tailors the update

Our Approach

Metadata Analysis

- Memory layout and and size
- Symbols
- Version information
- Tasks configuration
- Modules dependencies
- Synchronization points
- Worst case execution time
- Worst case response time
- Interference time
- Priority inversions

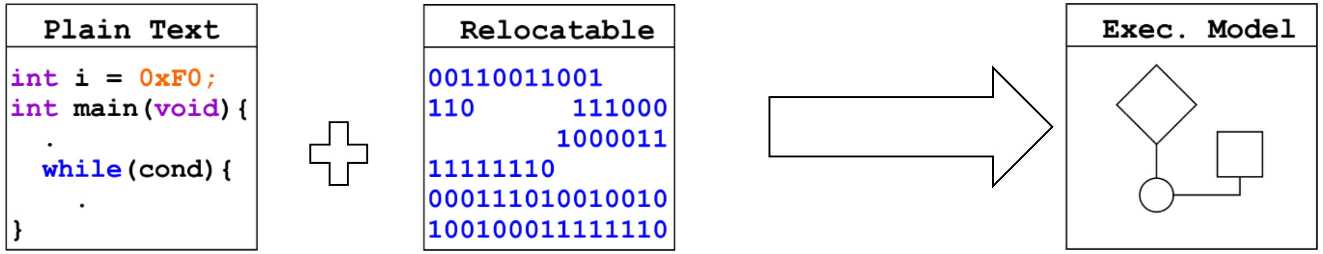


Our Approach

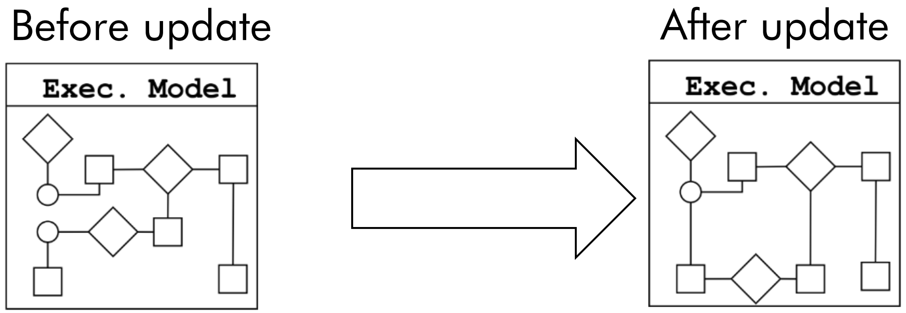
Execution Model

- Describe software execution

  - Individual modules
    - Tasks WCET
    - Synchronization pairs



  - Whole System
    - Tasks WCRT
    - Potential deadlocks or starvations



Our Approach

Updates will only be accepted if they are compatible with the system.

Compatibility

- Pluggability: Dependencies
- Interoperability: Execution

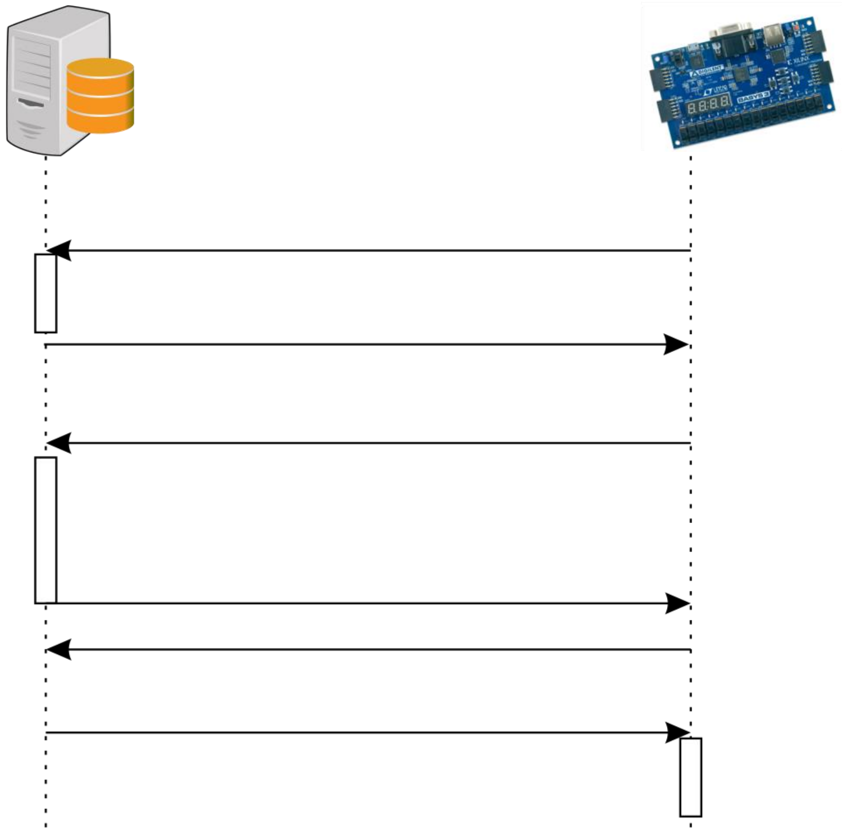
Our Approach

Update Protocols

- Metadata exchange
- Find good trade-offs
  - Generic updates x Client processing

Metadata

- List of installed modules and respective versions
- Global symbol table
- Memory layout
- Execution models



Our Approach

Metadata Location

- Server
- Client
  - List of installed modules and respective versions
  - Global symbol table
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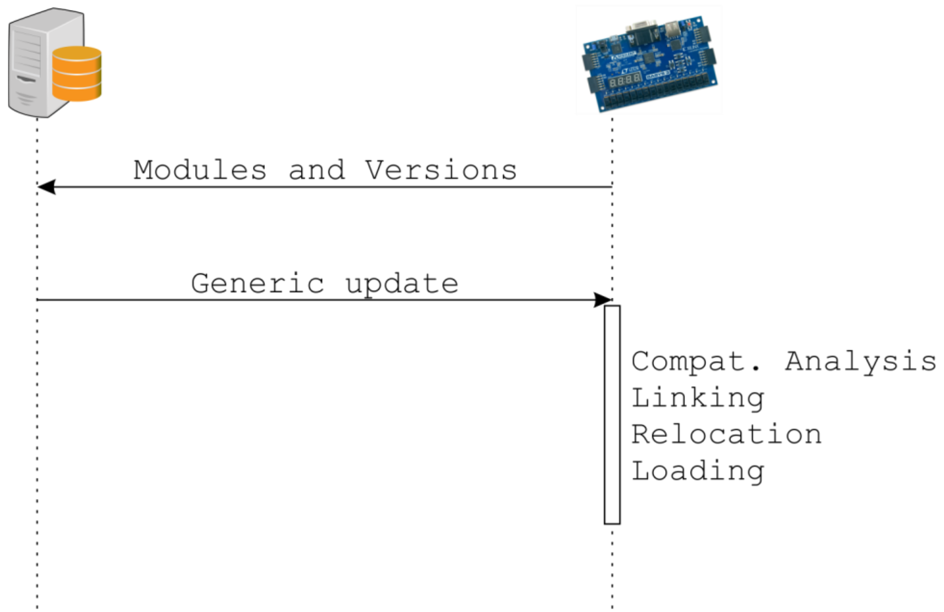
  - Execution models



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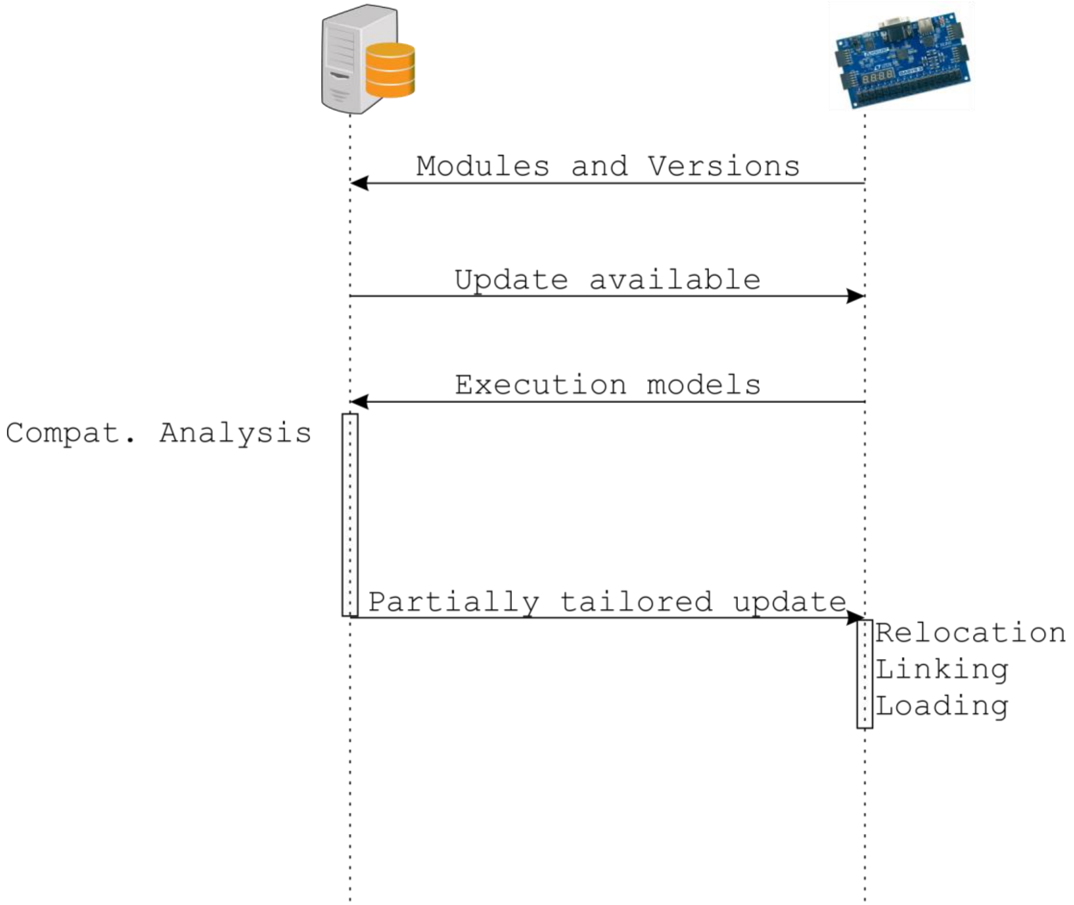

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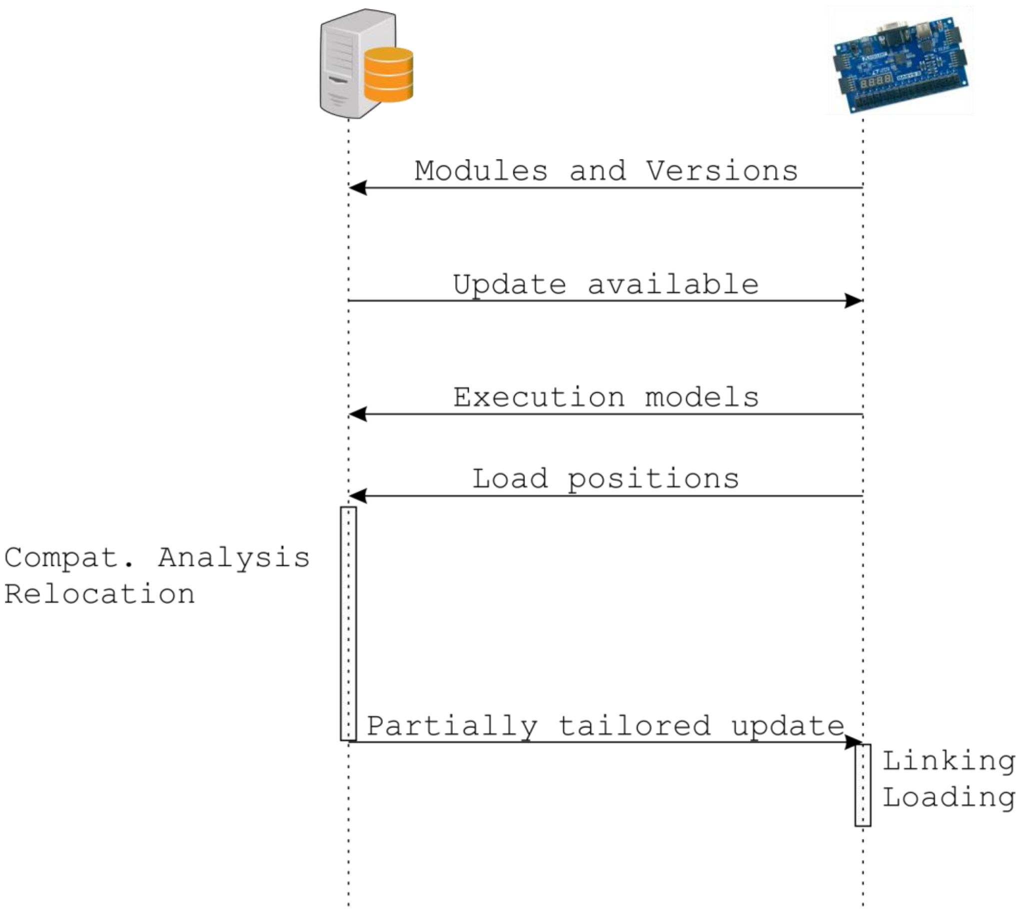

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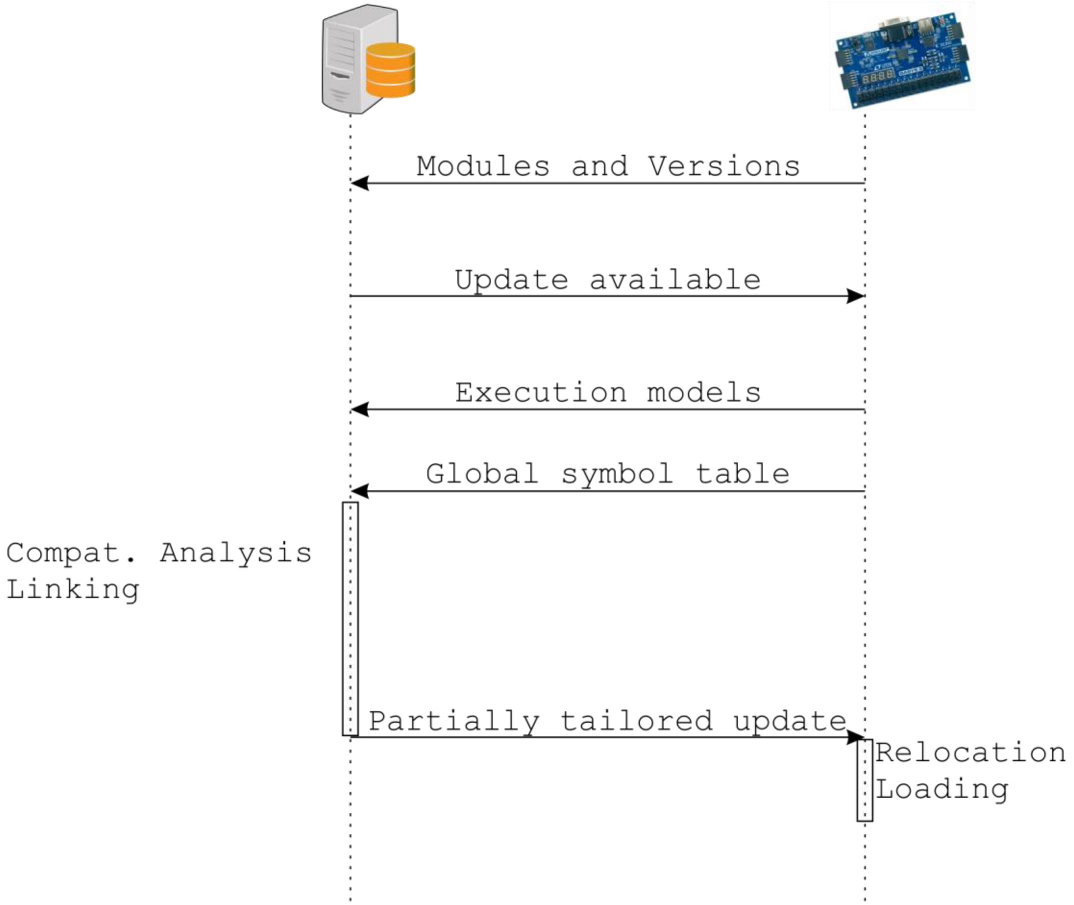

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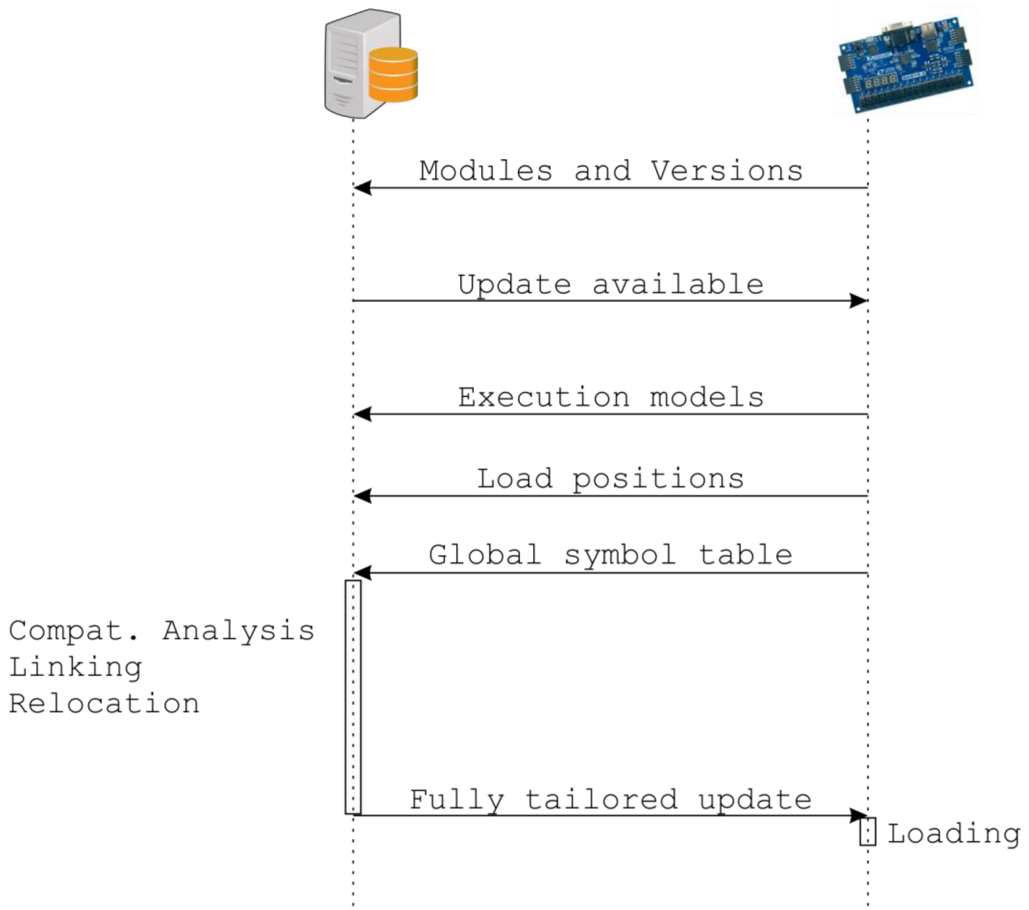

Our Approach

Metadata Location

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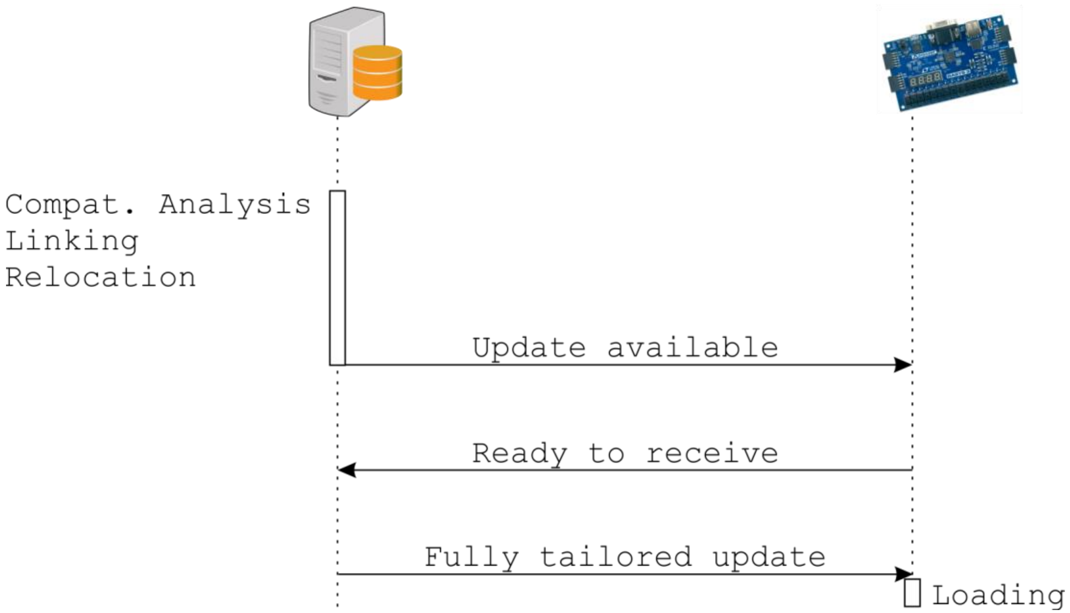
- Client



Our Approach

- Investigate overhead with diverse update protocols.
- Define what performance classes of devices will support given protocols.

Thank you!

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