Enabling eBPF on Embedded Devices Through Decoupled Verification

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BPF is Useful

Typical BPF Use Cases

- Networking
- Increased observability over the system
- Increased security
- Improve performance of systems
- Safely extend kernel

BPF is Useful on Embedded

- BPF is used for networking → Embedded systems used at the edge for sensor networks
- BPF is used for observability → Observability over embedded systems matters
- BPF is used to change kernel policy → Safely and dynamically change embedded behavior

New use cases will come in the future

Main Challenges to BPF on Embedded

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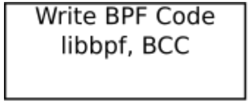

Write BPF Code
libbpf, BCC

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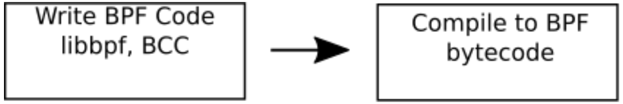

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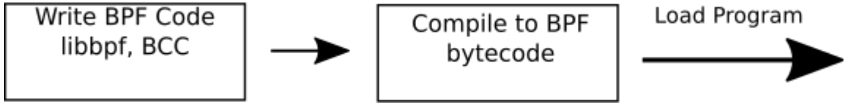

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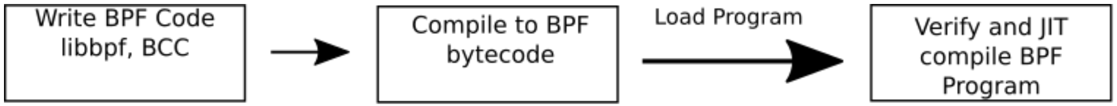

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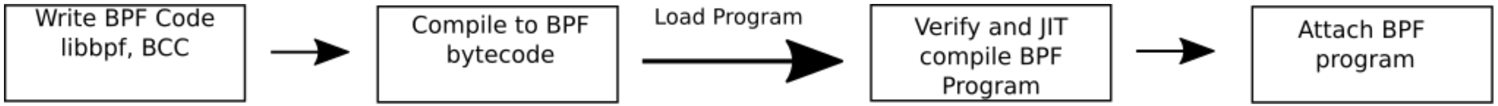

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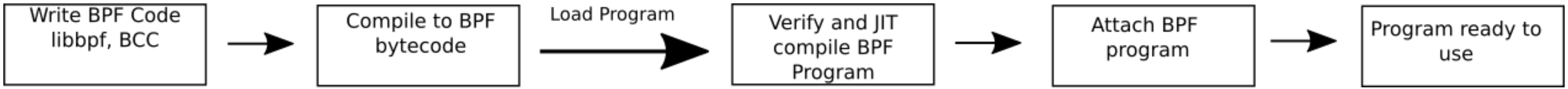

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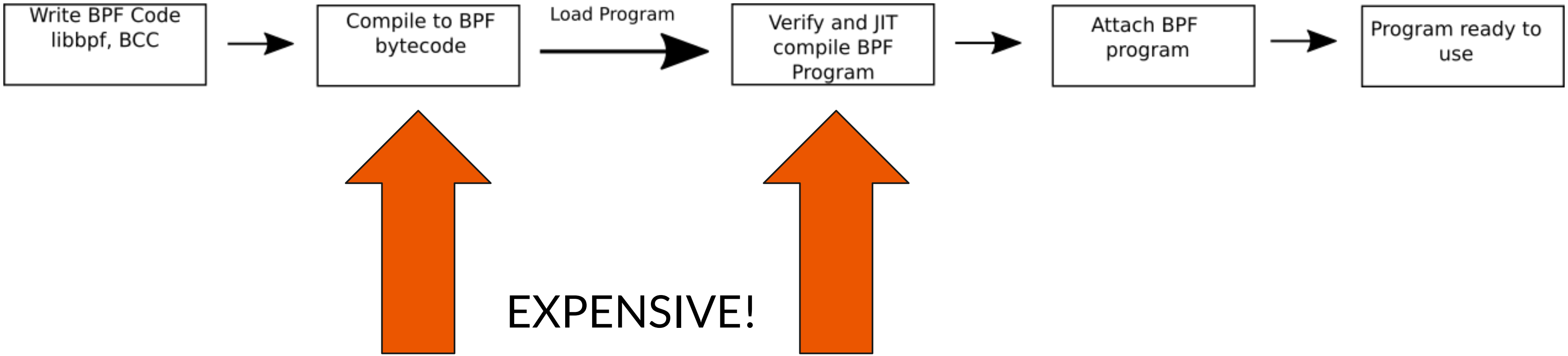

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Load Program

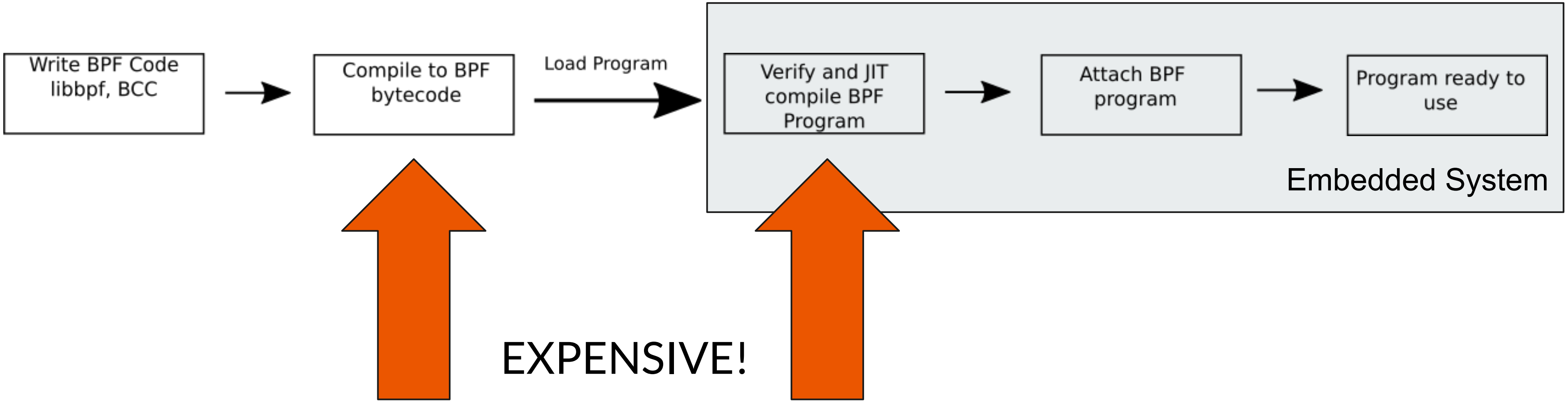
Verify and JIT compile BPF Program

Attach BPF program

Program ready to use

EXPENSIVE!

Main Challenges to BPF on Embedded



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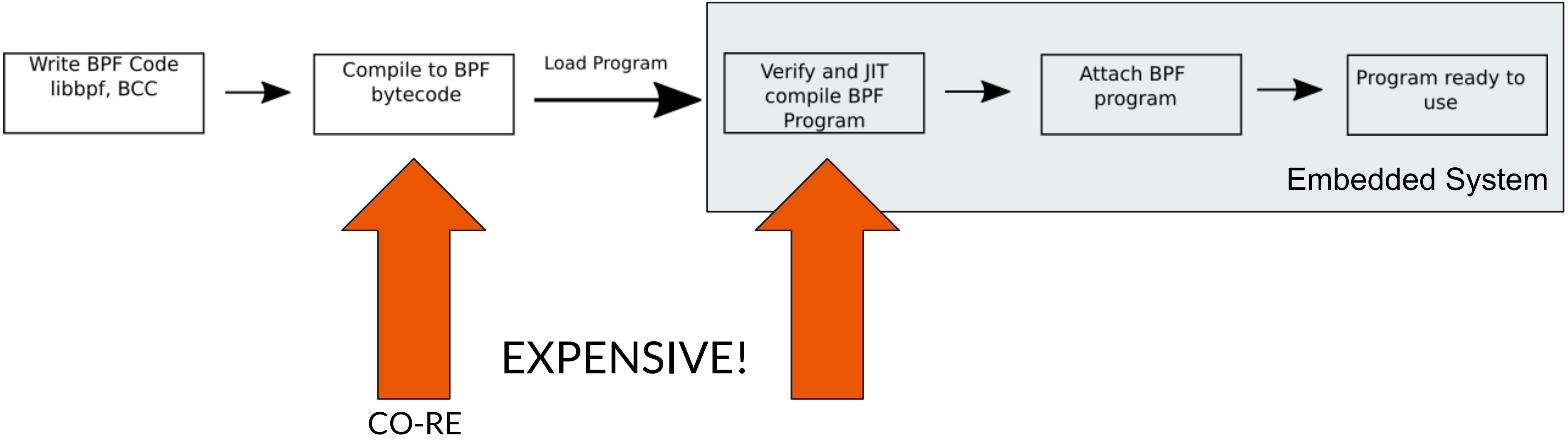

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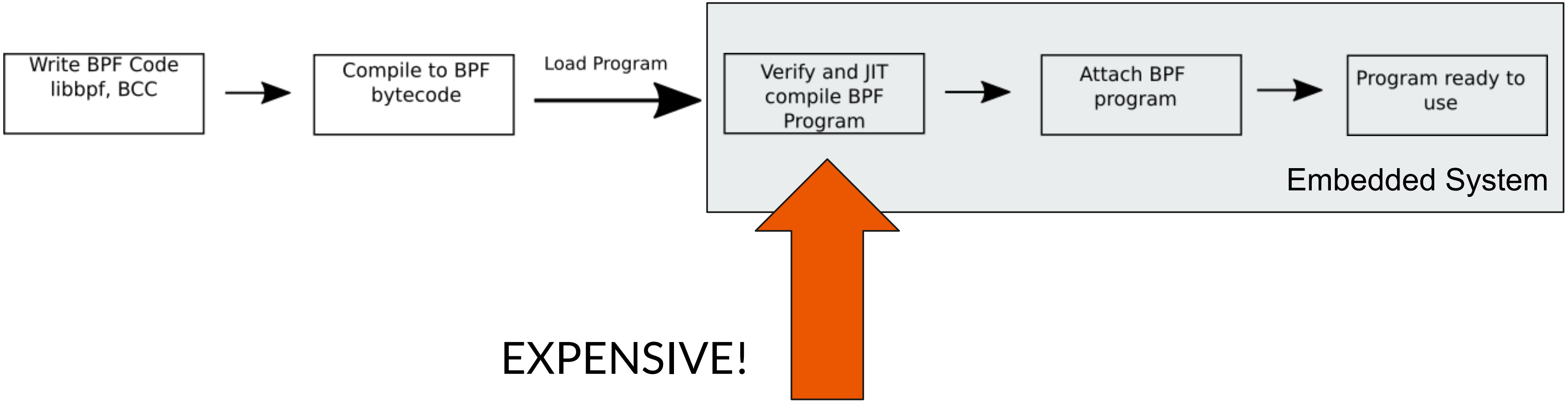

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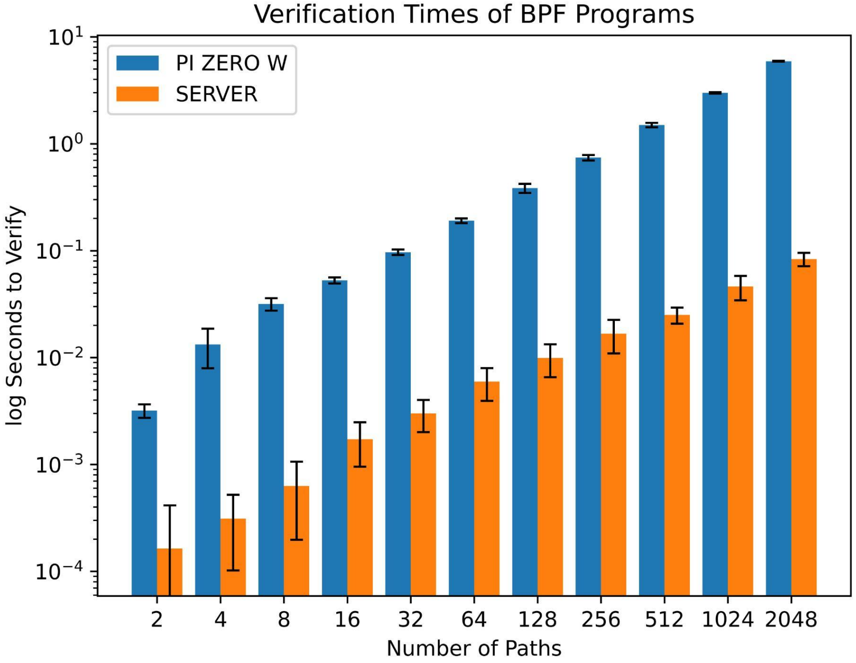
EXPENSIVE!

Verification is Expensive

- Verification grows with number of paths
- Occurs at load time, every time

- 20 to 70 times slower
- Weaker processor verifies slower
- Close to 10 seconds for 2048 paths
- BPF programs will not become simpler



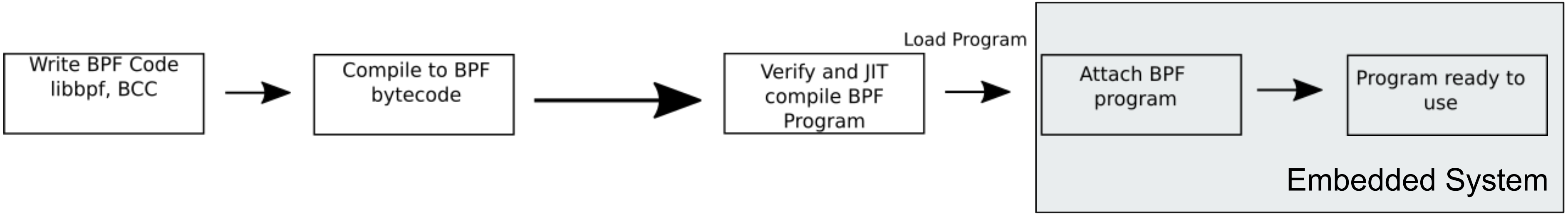
Key Insight

BPF program verification need not happen at load time

- Only verify programs one time
- Can verify programs at any time
- Can spend as much CPU time as needed

We achieve this by decoupling verification

Decoupled Flowchart



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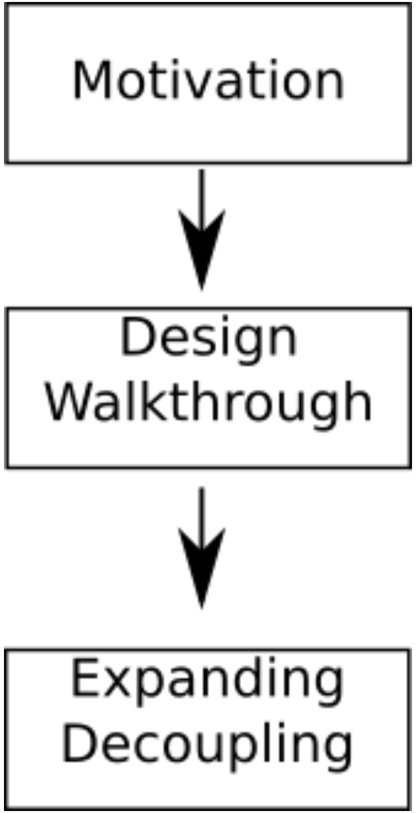
Talk Roadmap

- Motivate BPF on embedded
  - Challenges
  - Opportunities
- Walkthrough our decoupling design
  - Key points and design goals
- Discuss how decoupling goes beyond embedded
  - Verification as a service
  - Expanding the BPF Ecosystem



Design Goals

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- Ensure verifier trust
- Enable pre-verified programs to be loaded

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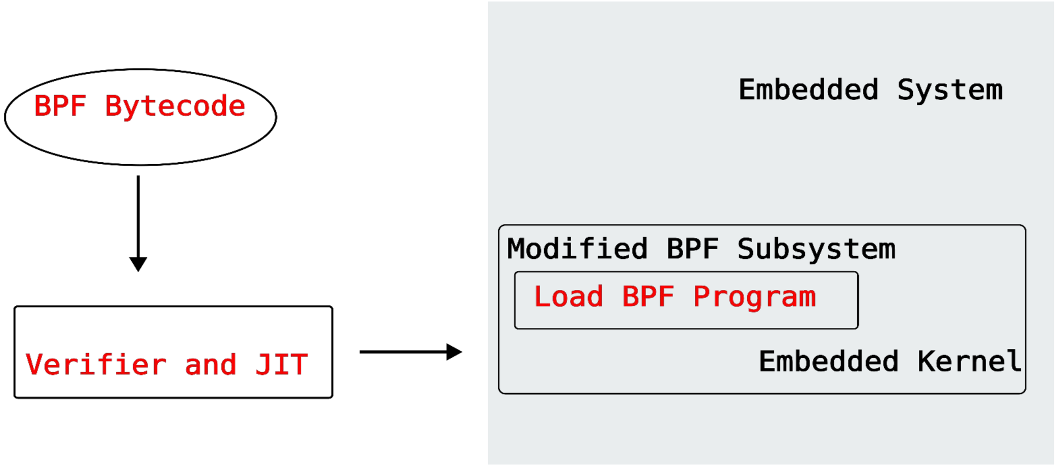
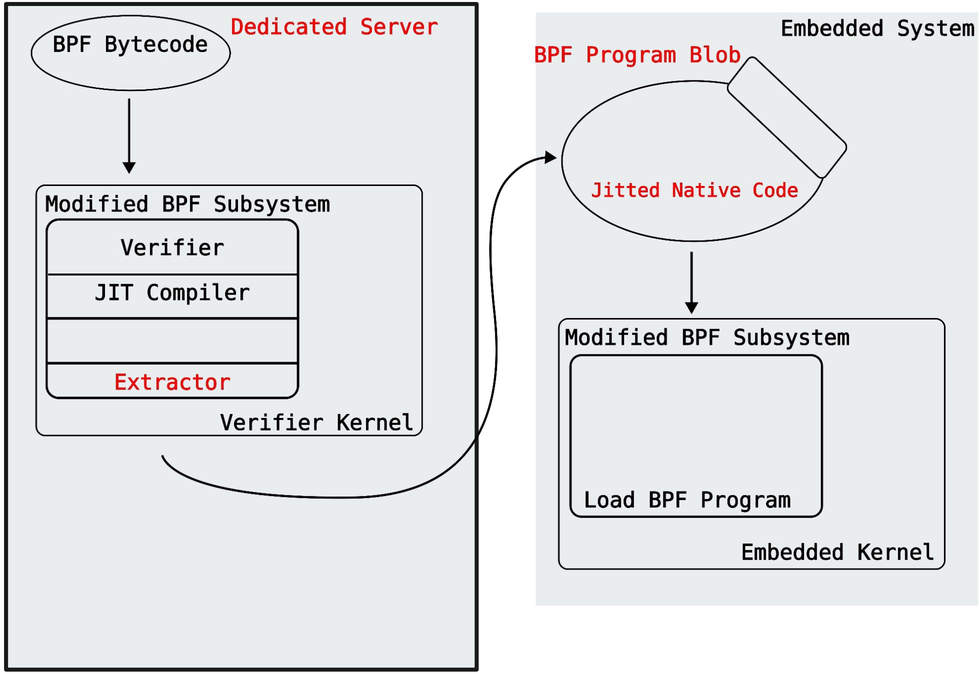


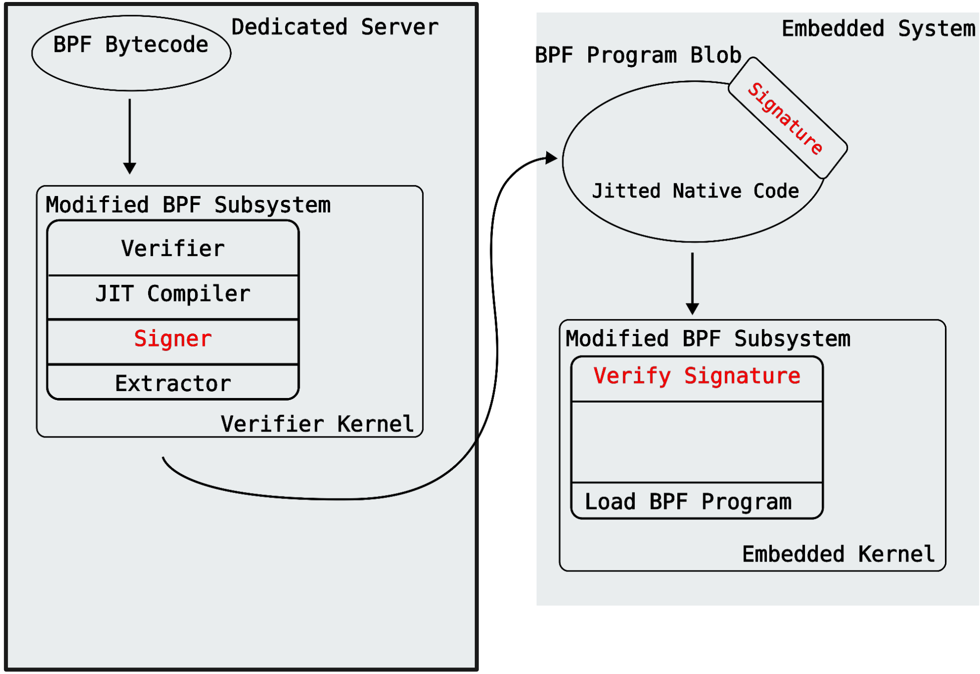
Ensuring Kernel Compatibility

- Use the in-place Linux kernel verifier and JIT
- Ensure that the program would have been verified on embedded device
- Keeps all the safety properties of the current verifier
- Produce what would have been created if the embedded kernel verified the program



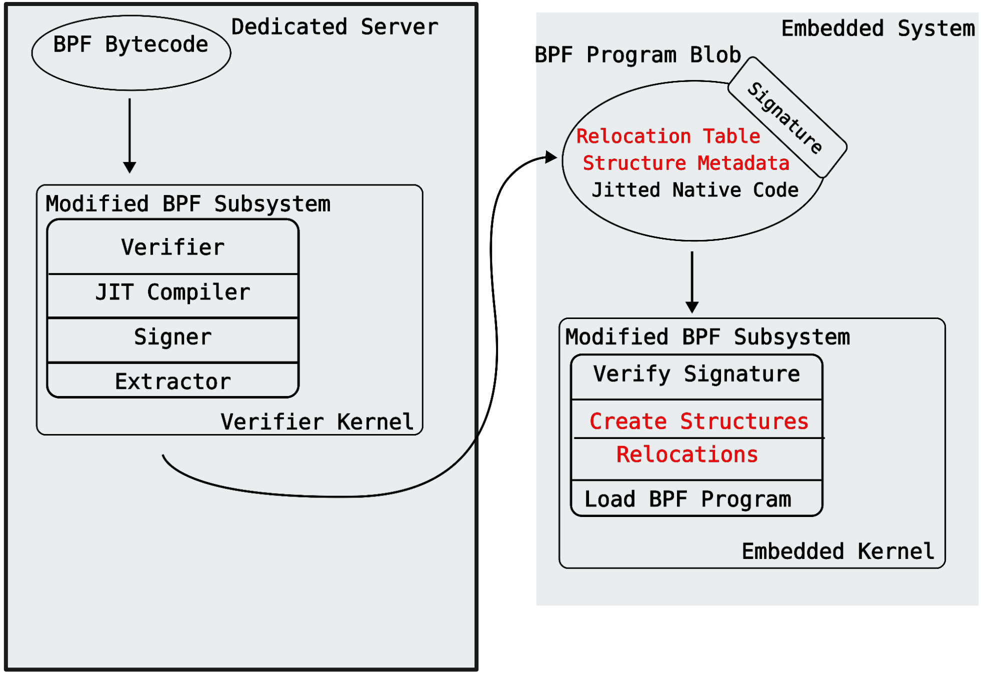
Ensuring Trust

- A user cannot trust the pre-verified code on its own
- Ensure trust by signing the pre-verified blob
- If the user trusts the verifier then they can load



Enabling Loading

- Helper functions and maps need to be relocated
- Emit metadata that specifies helper id and where the relocation needs to be done
- Maps are still in progress
- Resolve these on the embedded kernel



Decoupling is Deeper than Embedded

Decoupling opens up new opportunities in BPF world

- Increasing BPF program complexity
- Verification as a service
- Expanding the ecosystem

Raising BPF Limits

- BPF program complexity is limited by the verifier
- Techniques to bypass this are clever, but clumsy
    - Separating program into smaller pieces to verify
- Decoupling allows us to increase these limits substantially
- Greatly increases the possible complexity of BPF programs

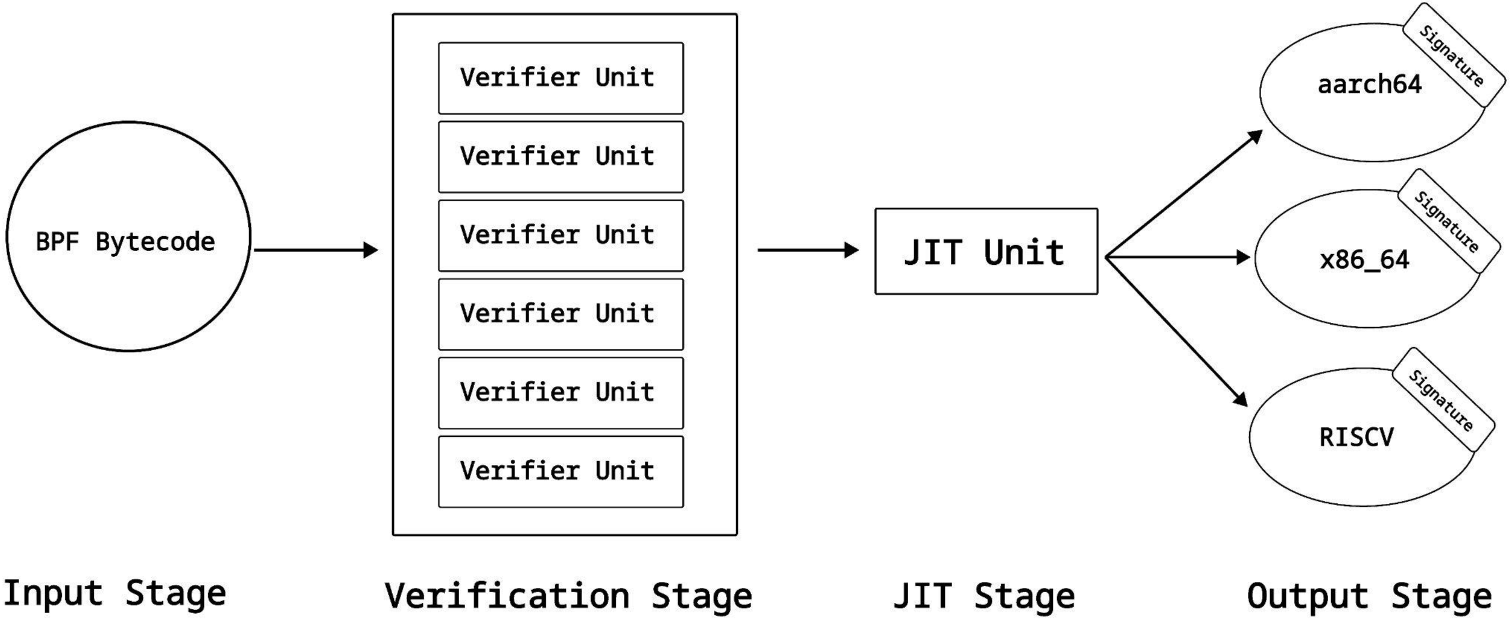
Verify Once Run Everywhere

- BPF wants to be Compile Once Run Everywhere
  - Allows for compatibility between similar kernel versions
  - Aids distribution of BPF programs
- End goal is to make it easy to load BPF programs
- With decoupled verification BPF can be Verify Once Run Everywhere
  - Extremely easy to load BPF programs
  - Computationally cheap

Expanding Ecosystem

- Current verifier and JIT are ad-hoc
- Decoupling better enables the use of alternative verifiers and JITs
- Alternative verifiers may be better than Linux verifier
  - Better time complexity
  - Ensure different properties
- Allow experimental/architecture specific JIT
  - Take more advantage of the specific hardware being run on

Distributed Verification



Takeaways

- BPF is useful on embedded devices
- BPF program verification does not need to be at load time
- Decoupling verification from load time allows
  - BPF programs on embedded
  - Expanded BPF ecosystem and program complexity
  - New types of services to support BPF