PLOS17

Annotations in Operating Systems with Custom AspectC++ Attributes

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Annotations in C/C++

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- $\approx$ 100 compiler-specific attributes
- Standard does not specify custom annotations or custom attribute behaviour

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[[tracing::call]] void some_func();      →  "[DEBUG] Running void some_func()"
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→ Discussion of use cases of custom annotations in OS development

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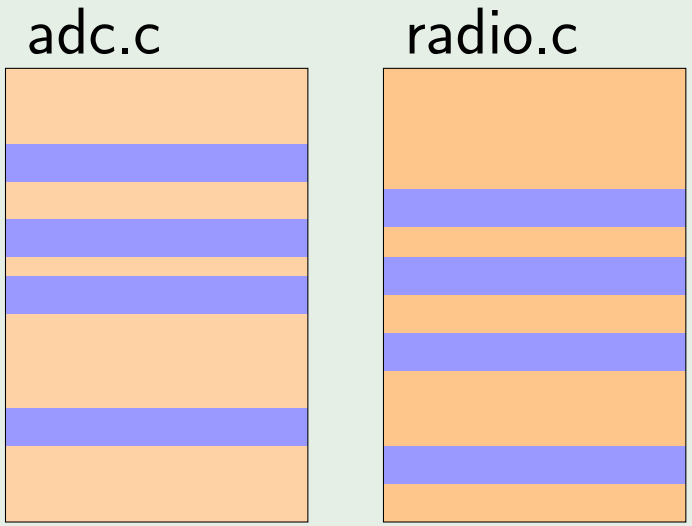
Components: ADC, Radio, Tracing



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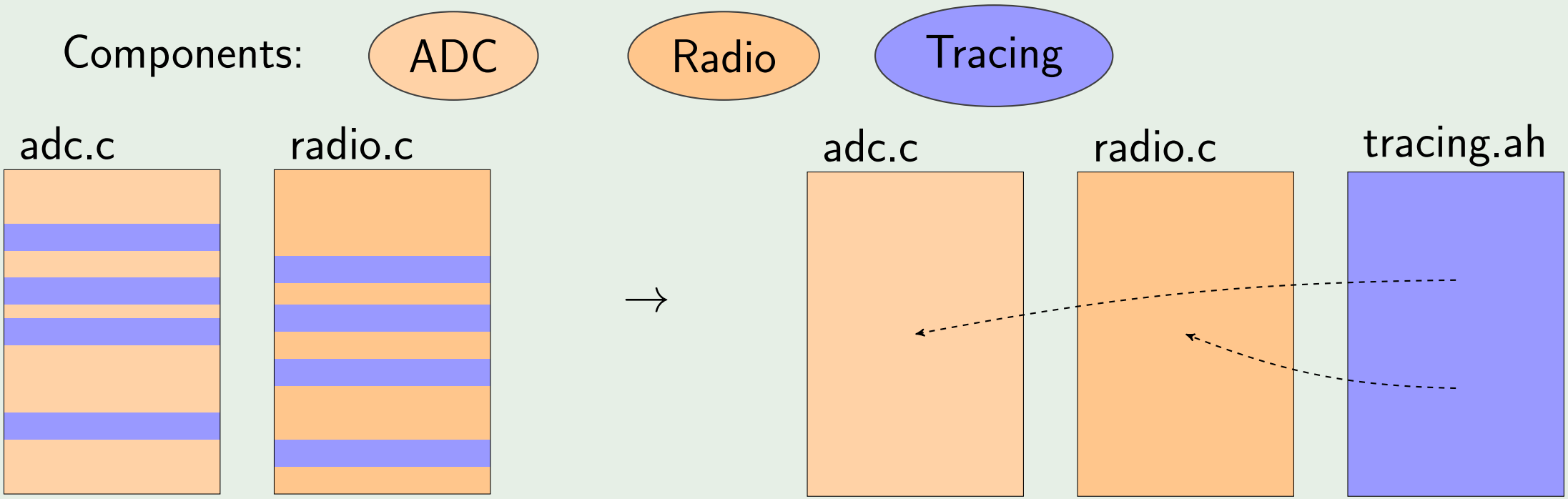

- Tracing code is **woven** into ADC and radio

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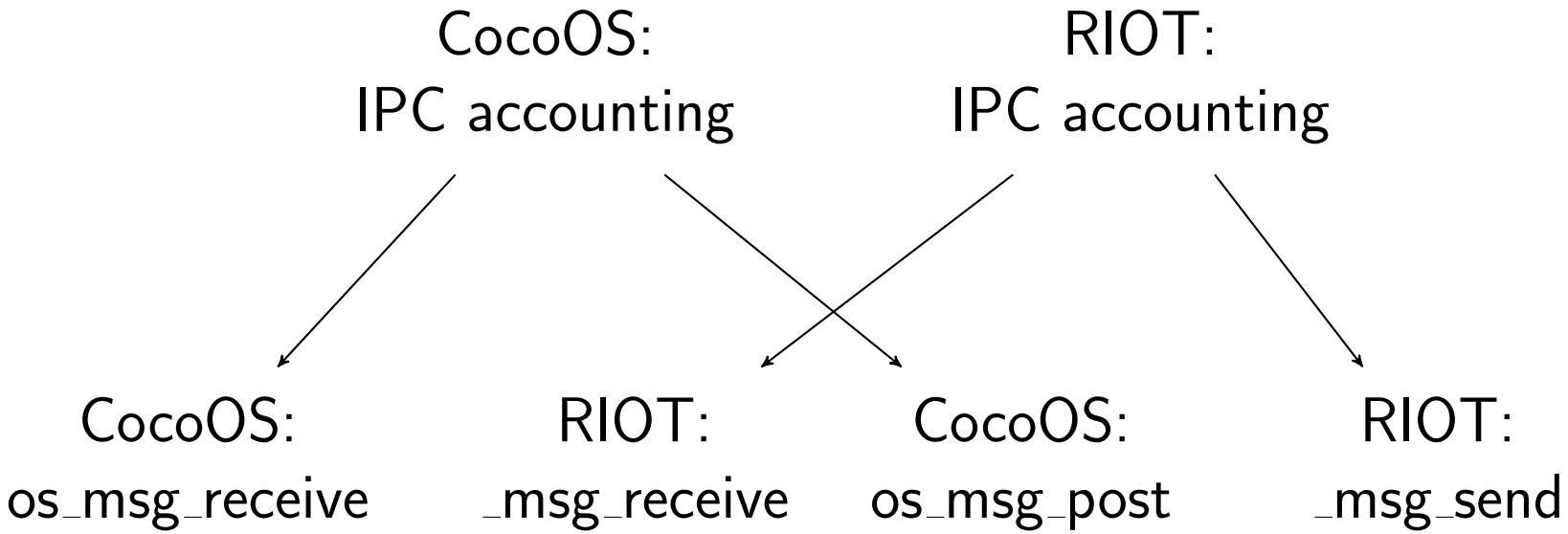
- Limitation: Cannot affect code generation by compiler
  - Custom attributes cannot set alignment, binary sections, . . .

Operating System APIs

- Annotations can also **describe behaviour** and serve as API



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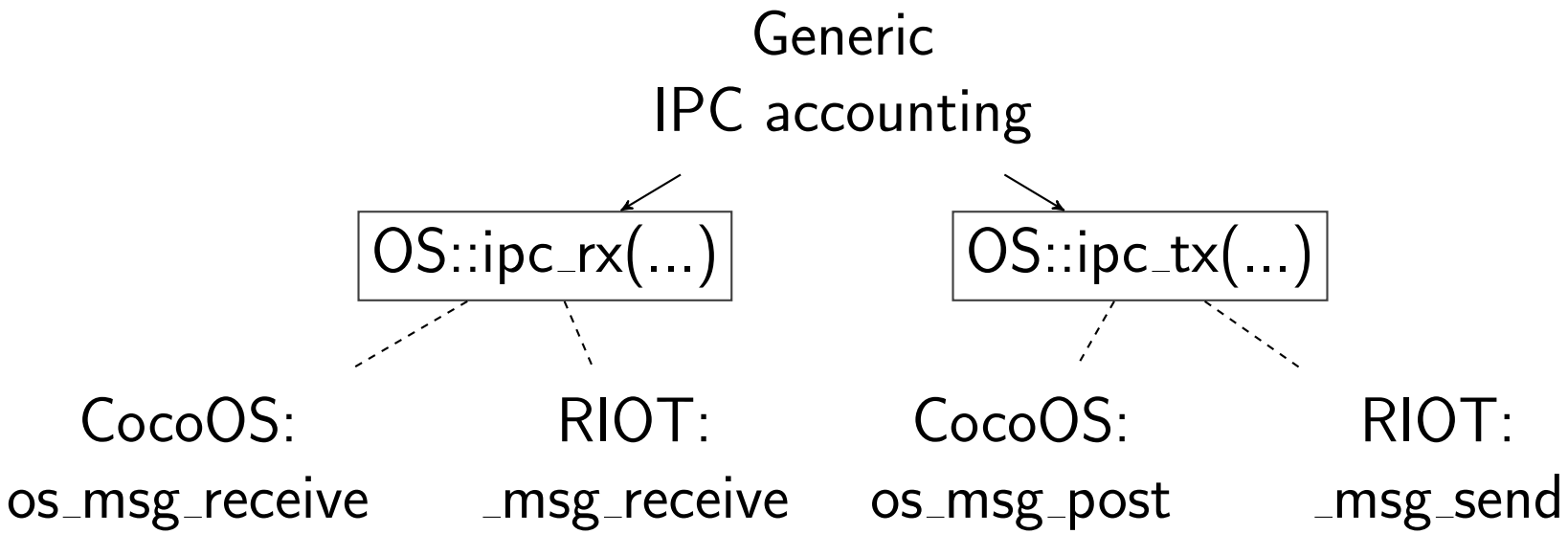

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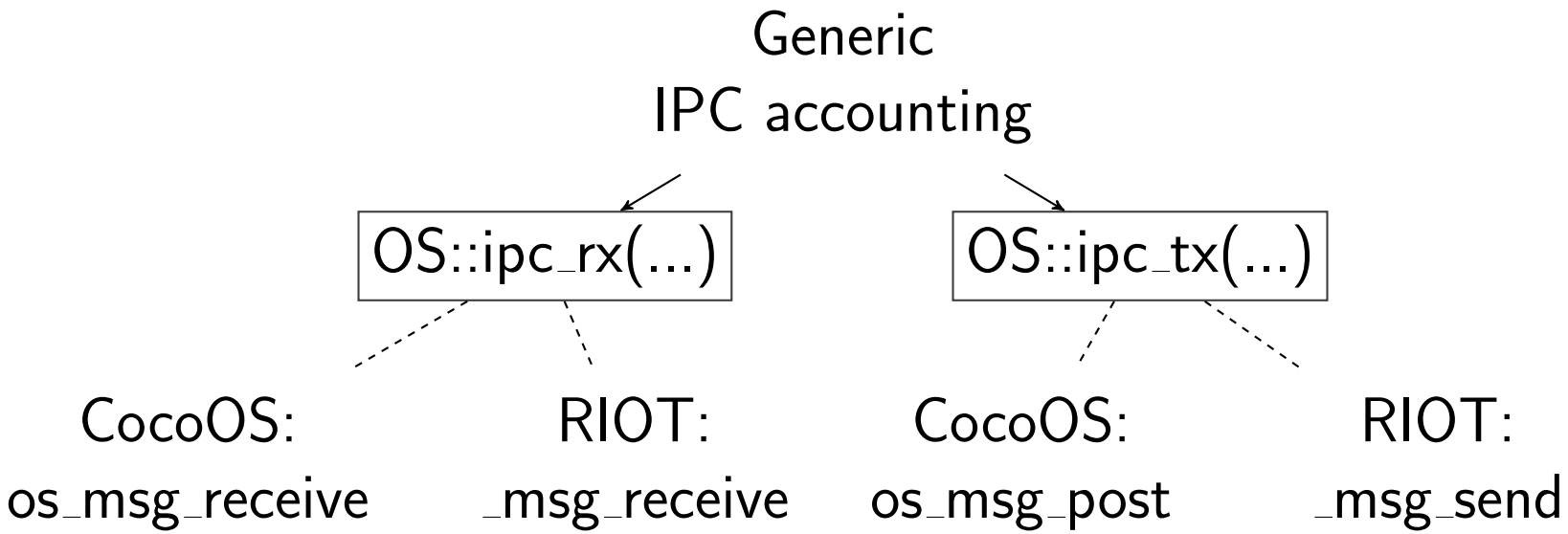

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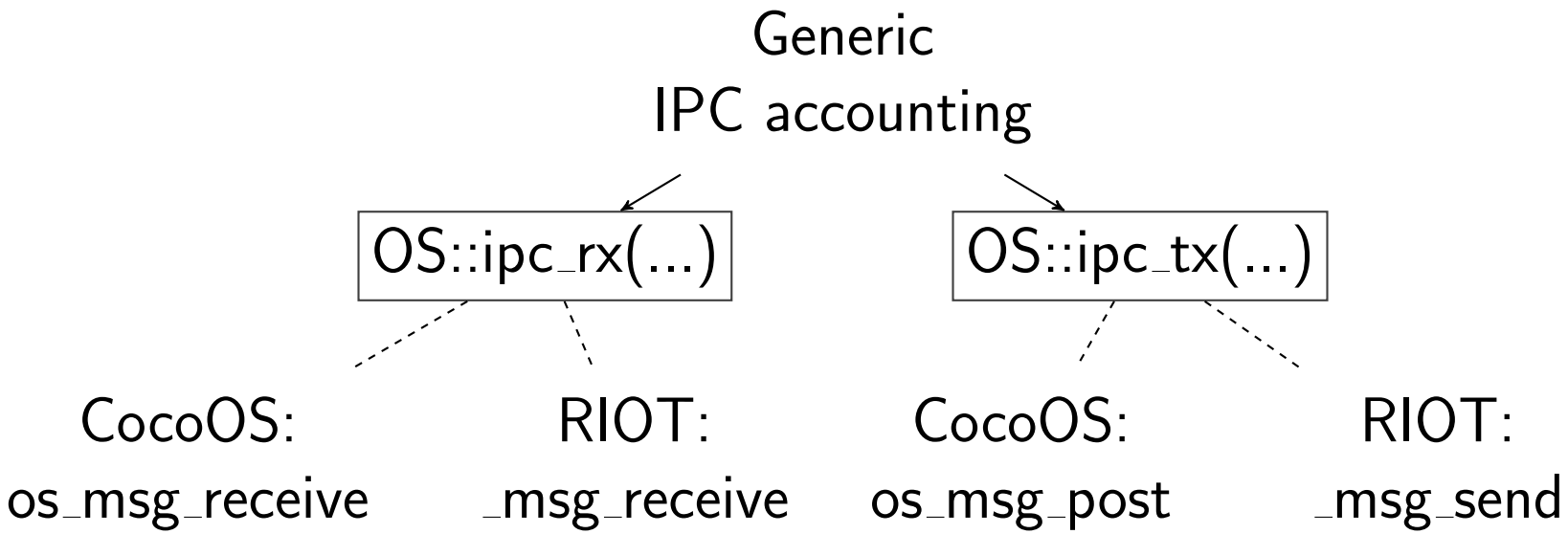

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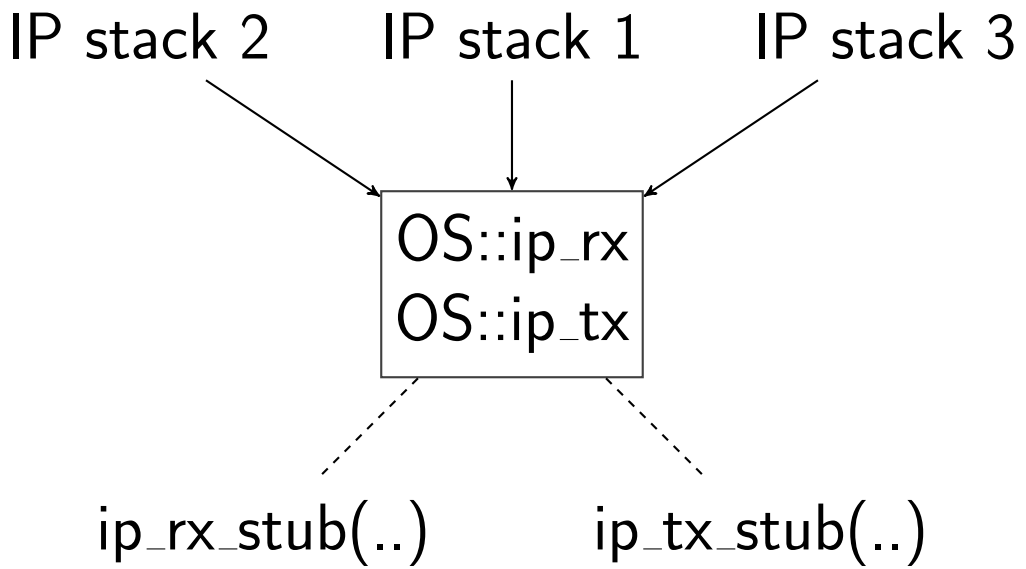

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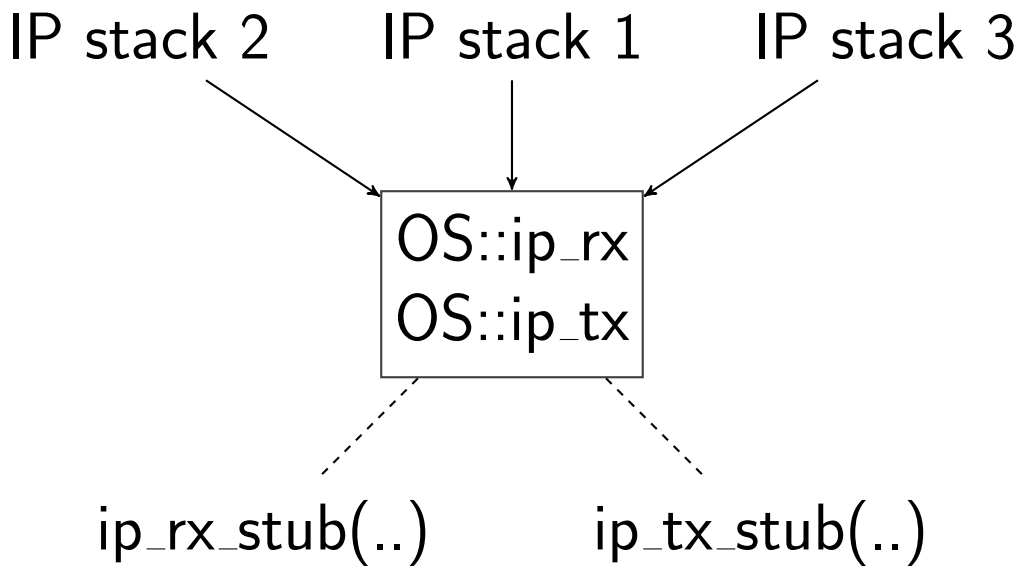

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- Modules need to match annotations
  - Moves adaption responsibility from system to modules
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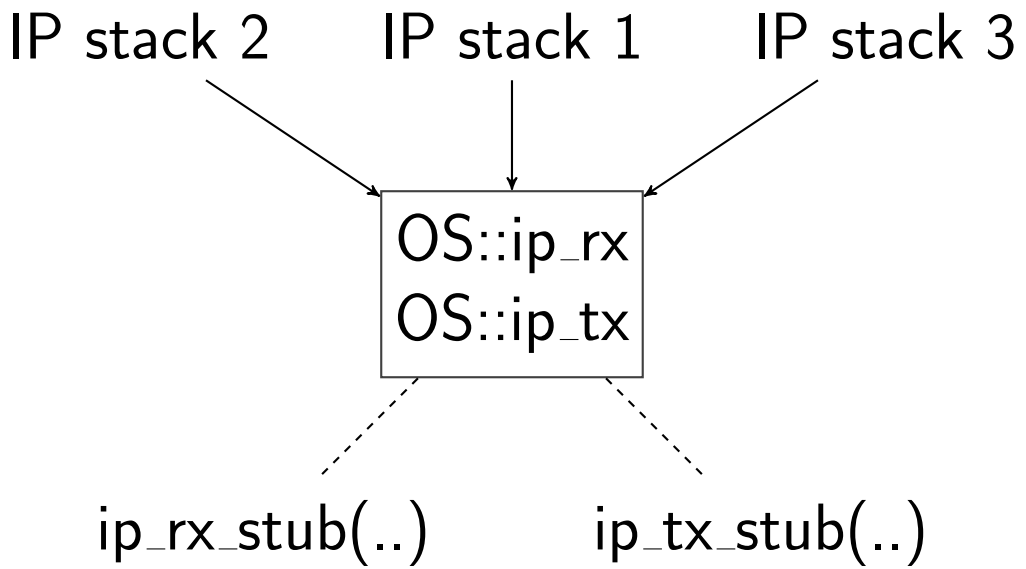

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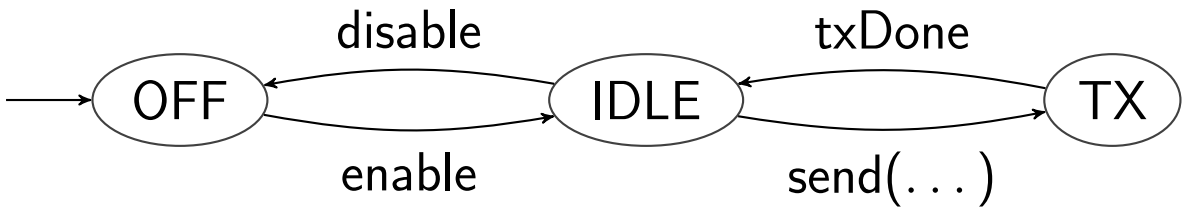

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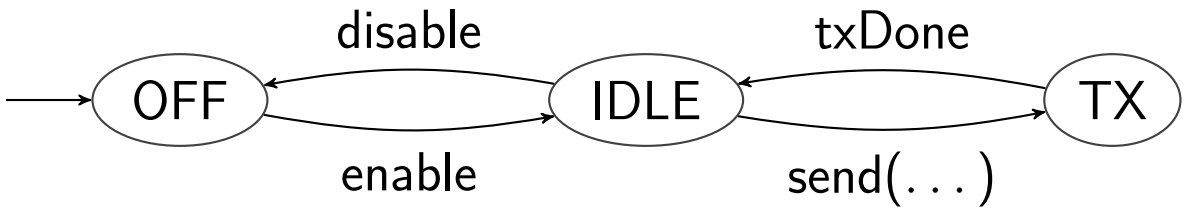

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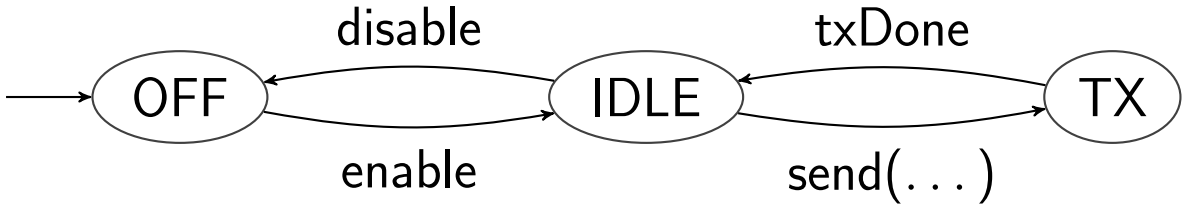

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  - But: implementation may evolve $\rightarrow$ model needs update
  - model inference from source code rarely captures entire model [GSB09]

Source Code and Model Co-Development

- Attributes allow embedding models into source code

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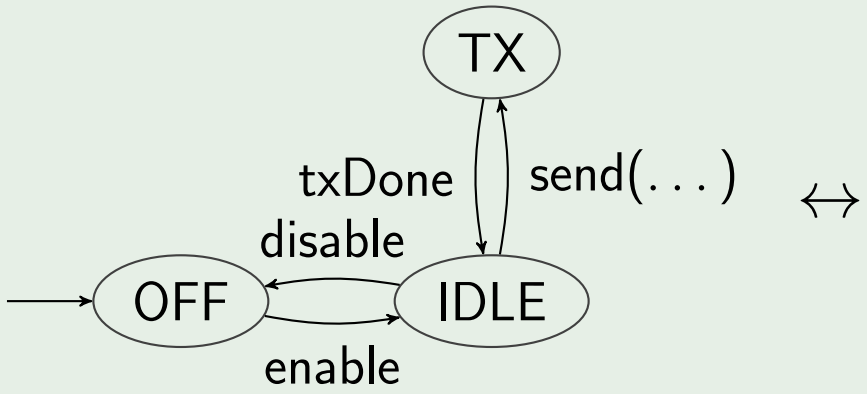

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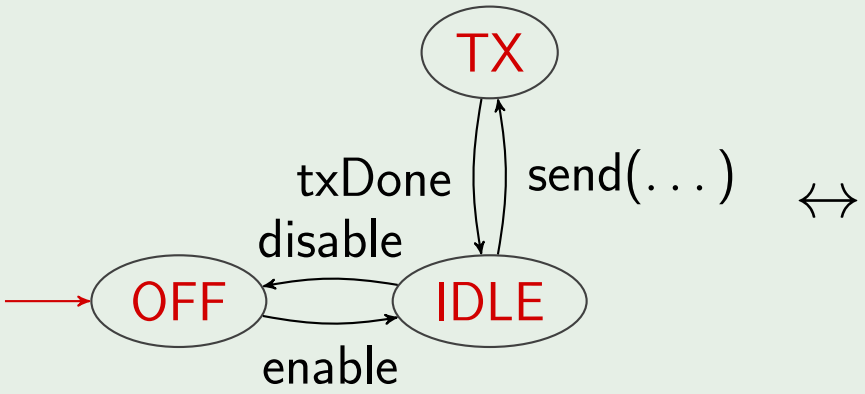

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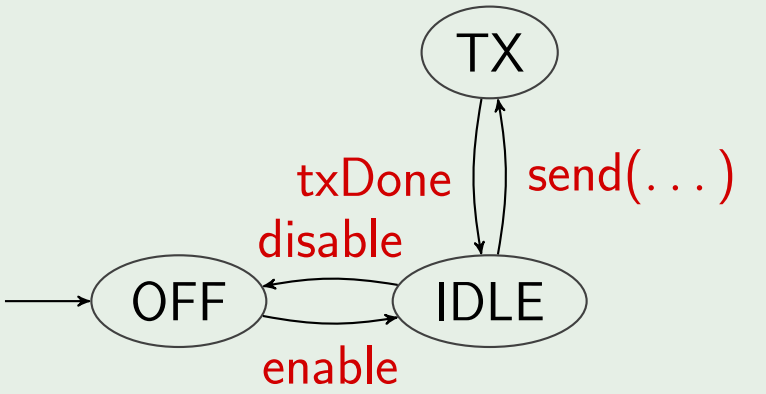

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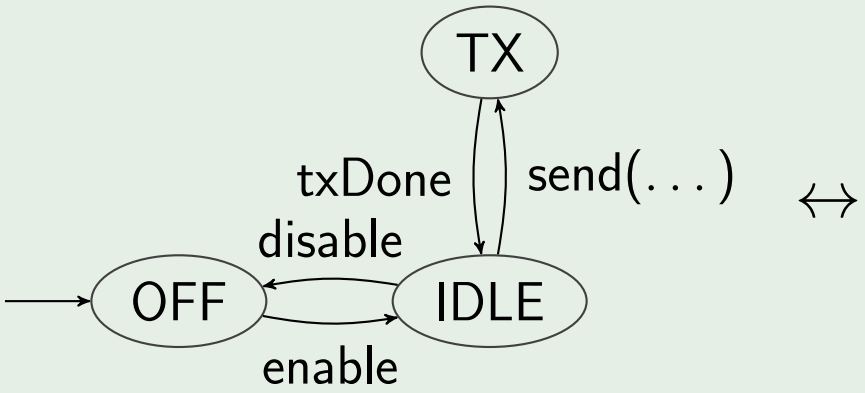

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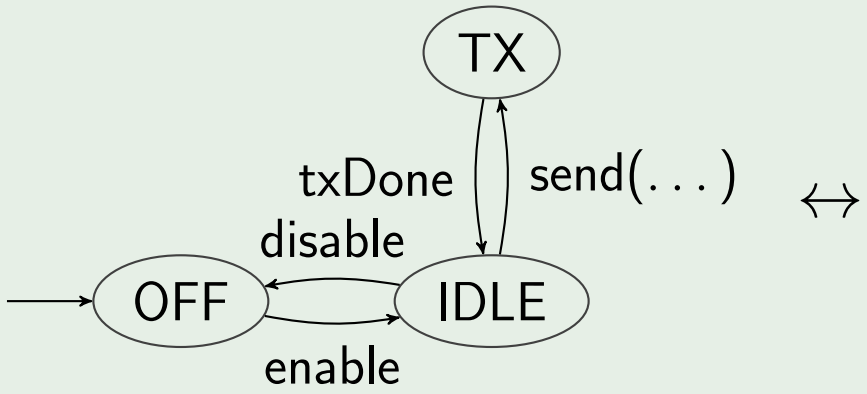

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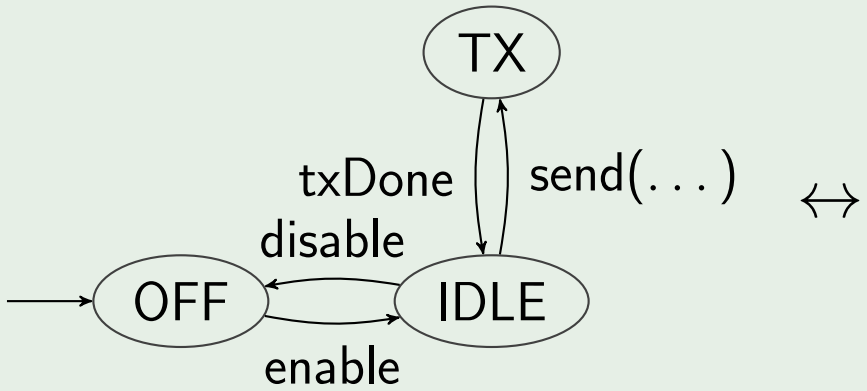

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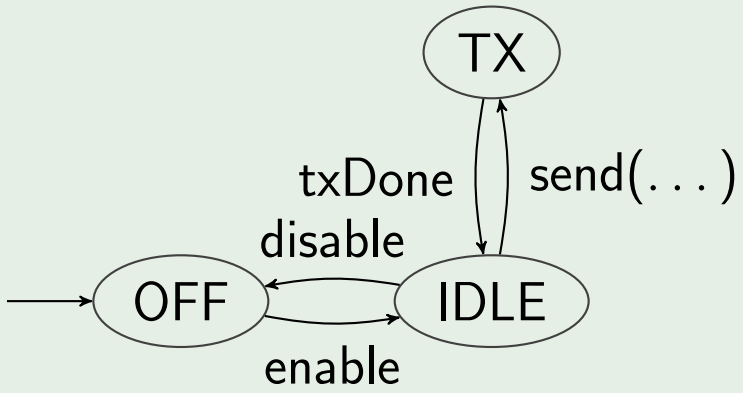

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- Can be made (partially) available at runtime by aspects
- Zero overhead when unused
  - Annotations can also be parsed by external tools

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  - Can be annotated and used with AspectC++ compiler
  - C++ backwards-compatibility possible with preprocessor macros
- C source needs to be adapted to C++
  - Tedious, but usually feasible
  - Depends on project size and amount of non-C++-compatible C code

Evaluation

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  - Function call tracing, deprecation handling and interrupt control
  - IPC accounting via system API
  - Energy modelling of peripherals
- Compilation with `-Os`

$\rightarrow$ Annotations without aspects cause zero runtime overhead

Evaluation

- Examples used on three embedded OSes: CocoOS (C), RIOT (C) and Kratos (AspectC++)
  - Adaption to C++ took < 1 hour for CocoOS and one day for most of RIOT x86
  - Retained full C compatibility in CocoOS
- Implementation of:
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  - IPC accounting via system API
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$\rightarrow$ Annotations without aspects cause zero runtime overhead

$\rightarrow$ Negligible difference between manual and annotation-based implementations

  - less than ± 0.1 % runtime size variation (assumed to be optimization corner cases)
  - No runtime aspect resolution

Conclusion

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- ... support source code and model co-development
- ... do not cause significant code size or runtime penalties
- Similar possibilities with Java/AspectJ, Python and C#
  - Resolved at runtime $\rightarrow$ execution time overhead
  - C/C++ more common for OS development
  - AspectC++ usable with any C++-compatible backend compiler

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