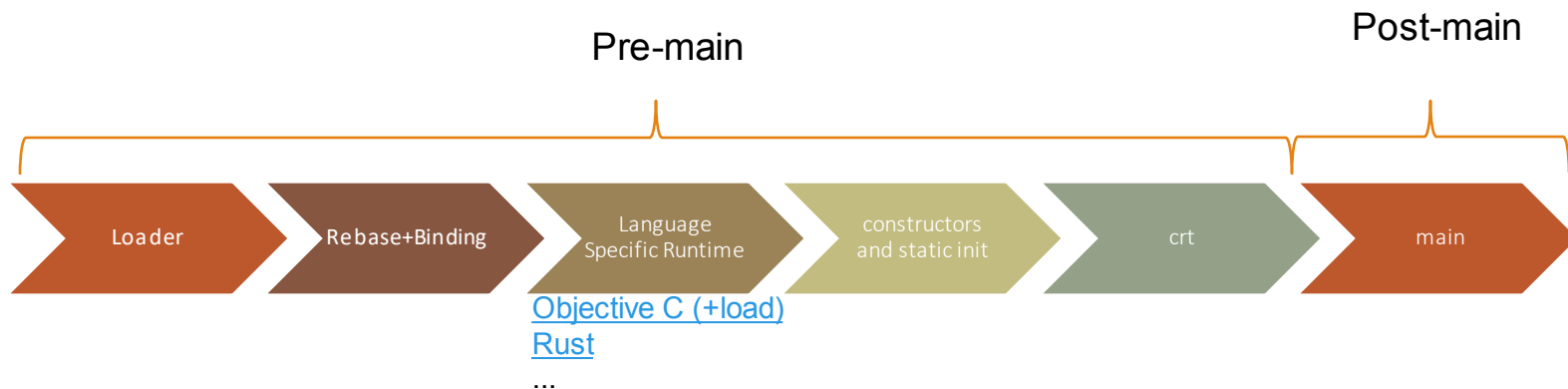# App Startup compiler optimizations and techniques for embedded systems

Program startup types

- Cold start
- Warm start
  - Cached/Prewarmed state
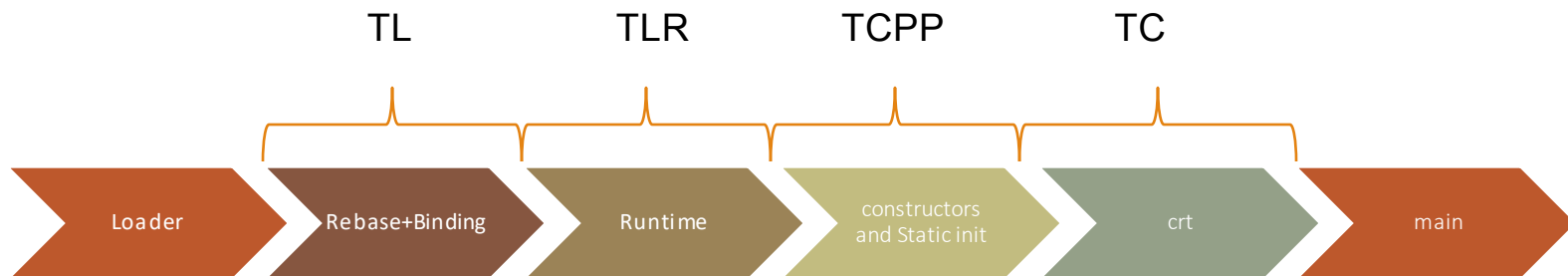- Hot start

Program launch sequence

Pre-main

Post-main

| Loader | Rebase+Binding | Language Specific Runtime | constructors and static init | crt | main |

Objective C (+load)
Rust
...

Measuring launch time spans

◦ By inserting timers wherever possible

Helps with
◦ Detect regressions
◦ Find bottlenecks

Measuring launch time spans

TL = Time to finish Loading the binary into memory

TLR = Time taken to execute Language runtime code

TCPP = Time taken by C++ static initializers and static constructors

TC = Time taken by the C runtime

Launch time is affected by

- TL
  - Page faults
  - extern functions
- TR
  - Language runtime, pre-main methods
- TCPP
  - Static initializers and attribute constructors
  - C++ standard library static constructors
- TC
  - C runtime library setup

TL = Time to finish Loading the binary into memory
TLR = Time taken to execute Language runtime code
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TC = Time taken by the C runtime

Launch time can be improved by

- TL
  - Reducing Page faults
  - Reducing number of rebases and bindings
- TLR
  - Reducing work done by the language runtime
- TCPP
  - Reducing number of static initializers and static constructors
- TC
  - Tiny

TL = Time to finish Loading the binary into memory
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Page faults

Measuring page faults

- getrusage
  - `struct rusage::ru_majflt`
- task_info
  - `struct task_events_info::faults`
- ps
  - `majflt`

Compiler optimizations that helps reduce page faults

- Compiler optimizations to reduce binary size (page faults $\propto$ binary size):
  - `-Oz, -Os`
  - `-fno-exceptions`
  - `-fno-rtti`
  - `-flto, -flto=thin`
  - Identical code folding (function merging)
  - Machine outliner
  - Devirtualization
- Reduce working set size
  - hot-cold-splitting

Other optimizations that helps reduce page faults

- Order file
- Code restructuring and annotations

Order file

- Helps with spatial locality
- Order file is a line separated list of function names
  - Mangled names for C++

```
$ clang++ hellp.cpp -o a.out -O2
$ objdump -D a.out | bash_magic
_main
__put_character_sequence
__pad_and_output


$ cat hello.order
__ZNSt3__124__put_character_sequenceIc...
__ZNSt3__116__pad_and_outputIcNS_11char_traitsI...
_main

$ clang++ hello.cpp -o b.out -O2 -Wl,-order_file -Wl,hello.order
$ objdump -D b.out | bash_magic
__put_character_sequence
__pad_and_output
_main
```

Steps to generate order file

- Execute the program
  - Instrumented or Bare
- Collect traces
  - Sampling (ftrace, dtrace)
  - Instrumented (-finstrument-function-entry-bare)
  - lldb (set breakpoint on all the functions)
- Generate order file by merging traces
  - Functions, static initializers
- Build the app with order file
  - `ld -order_file <file> -order_file_statistics <args> <binaries> -o a.out`

Code restructuring and annotations

Early evaluation
- `constexpr` (C++)

Lazy evaluation
- Creating functions objects
- Set of functions -> Hashmap<Key, Lambda Function>
- Moving the code not used in startup to a separate shared library

Caching
- Possibly with value profiling

Measuring rebases and bindings

- Rebases
  - `objdump [-macho] --rebase Binary | wc`
- Bindings
  - `llvm-objdump [-macho] --bind Binary | wc`
  - `llvm-objdump [-macho] --lazy-bind Binary | wc`
  - `llvm-objdump [-macho] --weak-bind Binary | wc`
- Using dyldinfo
 - `dyldinfo [-rebase|-bind|-weak-bind|...] | wc`

Reducing number of rebases and bindings

- Compiler optimizations to reduce rebases and bindings:
  - `-flto, -flto=thin`
- Making extern functions static when possible

Language runtime

Measuring impact of language runtime

- Use debugger or binutil tools to find the first called function
- Add 'start' timer
  - In the first function called.
- The 'end' timer
  - In the last function called or,
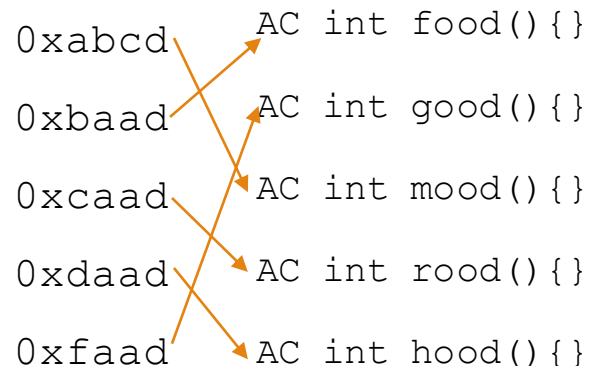 - In the first function of static initializer (next stage)
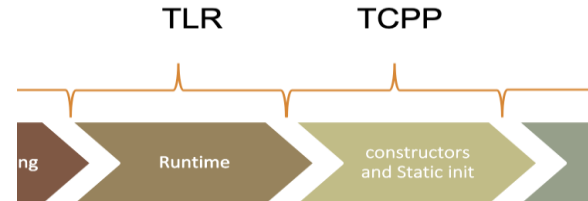
Reducing language runtime

- Removing pre-main functions as much as possible
  - Objective-C: Reduce number of +load in your program
- Do minimal work in pre-main functions
- Also helps with reliability of the app

Static initializers

Init array & SIOF

◦ Pointers to functions stored as array
  ◦ Static constructor
◦ Each function in the init array is invoked in a sequence
◦ The order init array is non-deterministic
  ◦ Depends on the order of definition, as well as order of linking

```
0xabcd          AC int food(){}

0xbaad          AC int good(){}

0xcaad          AC int mood(){}

0xdaad          AC int rood(){}

0xfaad          AC int hood(){}
```

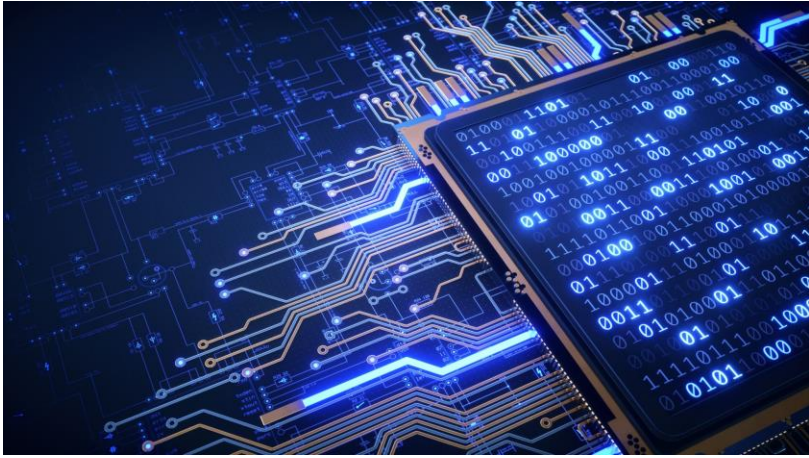# Measuring impact of static initializers

- Approach #1:
  - Find which function executes first, and last (with debugger, or binutil tools)
  - Insert timers
- Approach #2
  - Add two constructors with init_priority
    - [gnu linker] respects priority across translation units
  - Manipulate the init_array (mod_init_func) to reorder the constructors to begin and end of the array
    - Good Starting point: https://gist.github.com/C0deH4cker/80b53de22012146ea9d8

Reducing number of static initializers and attribute constructors

- Removing global static objects
  - Lazy evaluation by initializing the static object in function
- Removing unnecessary `__attribute__((constructors))`

References

- Profile-based Indirect Call Promotion
- Developer Tools #WWDC16
- Eliminating Virtual Function Calls in C++ Programs
- http://boost-sandbox.sourceforge.net/libs/proto/doc/html/boost_proto/users_guide/getting_started/hello_world.html
- Linkers and Loaders by John R. Levine
- https://man7.org/linux/man-pages/man2/getrusage.2.html
- https://www.gnu.org/software/hurd/gnumach-doc/Task-Information.html
- https://en.wikipedia.org/wiki/Lazy_initialization
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