Camlboot: debootstrapping the OCaml compiler

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About debootstrapping

The architecture of Camlboot

Interpreting OCaml

The MiniML language and compiler

Results

What is debootstrapping?

- *Source file*: preferred form for human editing and understanding
- *Self-bootstrapping* a compiler: compiling it with itself
  $\Longrightarrow$ Need (non-source) binaries of the compiler to build the compiler
- *Debootstrapping* a compiler: building a compiler without using its self-bootstrapped binaries

Why debootstrap? (1/4)

Trusting trust attack: bugs (or malicious code) can reproduce themselves through bootstrap binaries:

- some bugs seen in the wild, rarely reported,
- proofs of concept in Rust and Go,
- Induc virus: reproduces itself through Delphi compilers, discovered in the the wild in 2009, fortunately harmless!

Countering trusting trust: diverse double compilation

Diverse Double Compilation (DDC): use an independent compiler B to check that a deterministic compiler A is free from trusting-trust attacks.

- Compile A with both A and B
  $\Longrightarrow$ different binaries, but semantics should be the same.
- Compile A with the resulting binaries
  $\Longrightarrow$ should get the same output.

Why debootstrap? (2/4)

License question: is software free if:

- you need a proprietary compiler to build it?
- you need a proprietary compiler to build its compiler?
- there is no way to build it without using binaries at some point?

Why debootstrap? (3/4)

Reproducible builds: bit-for-bit identical results for software built twice in the same environment, allows caching and verification.

- Can it be trusted if the environment already contains the output?
- Is research really reproductible if it needs to know the result to reproduce it?

Why debootstrap? (4/4)

Semantics question: can we really specify the semantics of a program when some of it is hidden inside the compiler binary (and not source)?

```
let unescape_char c =
  match c with
  | 'n' -> '\n'
  | 't' -> '\t'
  [...]
```

How to debootstrap?

- Legacy path: replay compilation using a chain of old implementations
- Tailored path: use new implementations to shorten the chain

Key metric: total human work required

Writing a new implementation can be faster than finding and making old implementations work (also, much more interesting).

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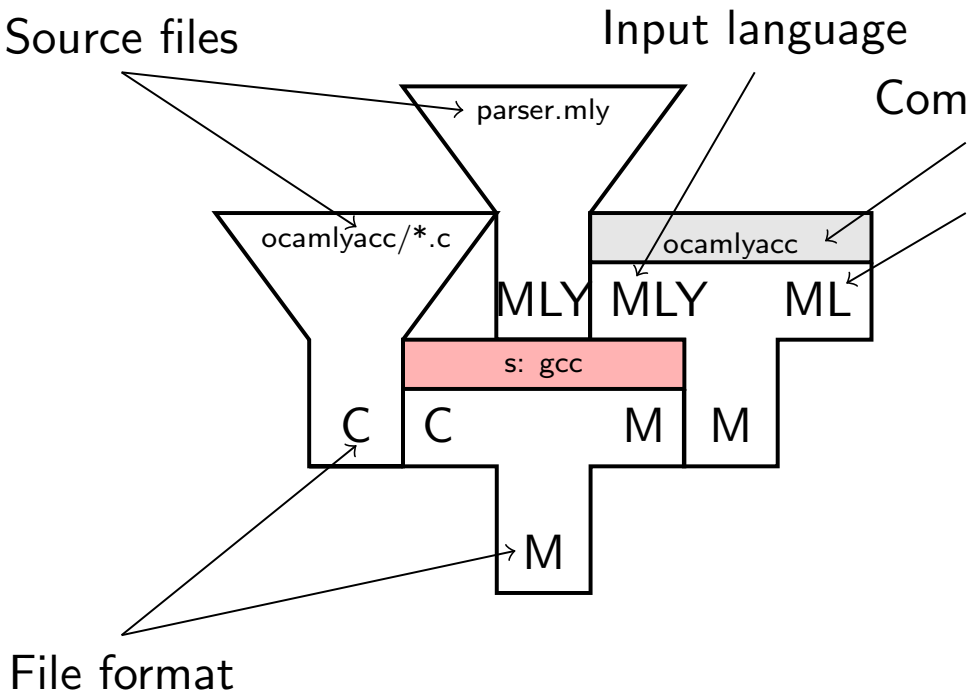
Components of Camlboot

- `interp`: An interpreter for almost all of OCaml, able to run the OCaml compiler
  - Written in MiniML, a subset of OCaml
  - Reuses the OCaml parser and lexer
- `minicomp`: A compiler from MiniML to OCaml bytecode
  - Written in Scheme
  - Very naïve
- A handwritten lexer to solve the bootstrap of `ocamllex`

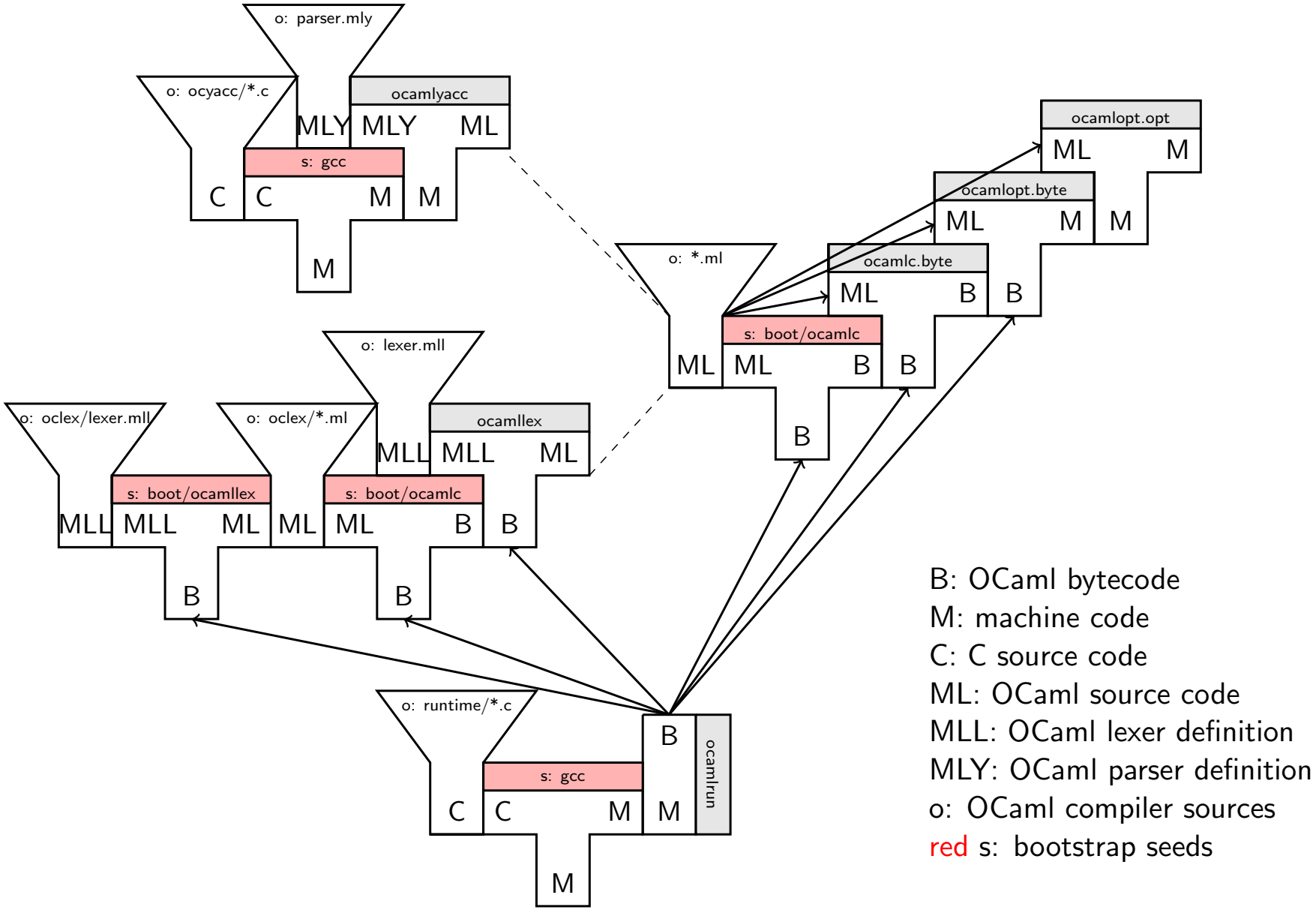
T-diagrams

T-diagram: graphical depiction of source file, output file, and compiler

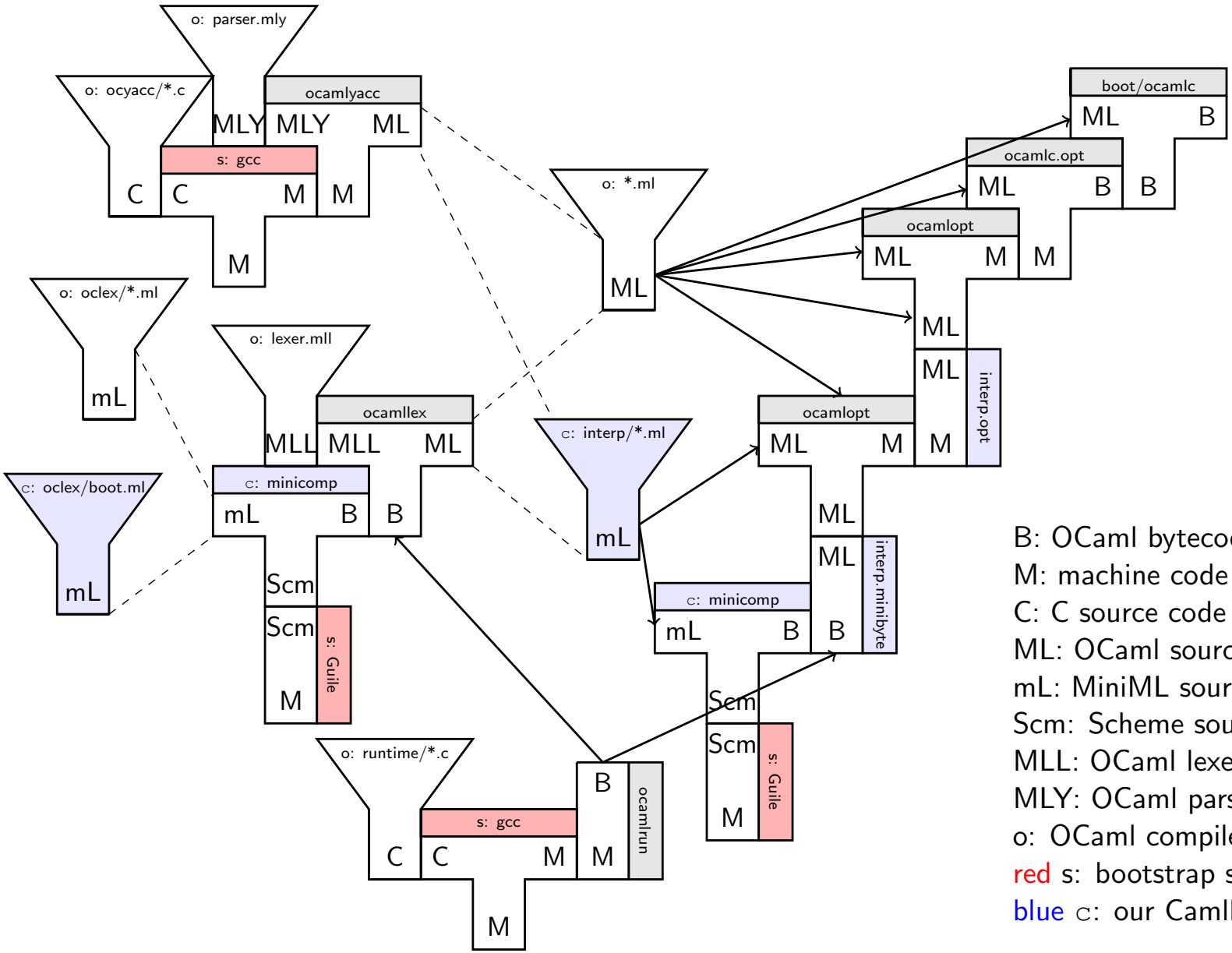


M: machine code.
C: C source code.
ML: OCaml source code.
MLY: OCaml parser definition.
red s: bootstrap seeds

Building OCaml 4.07



Building OCaml with Camlboot



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Scope of our interpreter

- Interprets the *untyped* syntax tree.
- Supports almost all of OCaml.
- A few approximations when the semantics depend on typing.
- Written in MiniML, ≈ 3000 lines of code, uses the parser from the OCaml compiler.

Why use OCaml (MiniML) instead of Scheme?

- Reuse the OCaml runtime primitives
  $\Longrightarrow$ simplifies the interpreter a lot.
- Writing a parser for the full OCaml language is complex
  $\Longrightarrow$ reuse the existing parser.
- A reference interpreter would be useful to the community.

```
let prims = [
  [...]
  ("caml_md5_chan",
   prim2
     Digest.channel
     unwrap_in_channel
     unwrap_int
     wrap_string);
  [...]
]
```

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The MiniML language

- Compiled to OCaml bytecode (ZINC abstract machine): can use runtime primitives, closures are easy to compile.
- No support for most advanced features.
- Deciding whether to support a feature or not:
  - Is it used in the interpreter?
  - Is it less work to support it than to remove its use in the interpreter?

The `minicomp` compiler

- Two-pass compiler, written in Scheme, ≈ 3300 lines of code
- First pass (*lowering*): pattern matching compilation, labeled arguments reordering, records and constructors turned into tagged blocks
- Second pass: compilation to bytecode, direct output to file with backpatching as necessary

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DDC for OCaml

- We performed diverse double compilation for OCaml 4.07.1.
- OCaml 4.07.1 is free of trusting trust attacks!

Compilation times

- First: basic build, interpreted `ocamlopt` directly compiles `ocamlc`

	First	Optimized	Parallel
`ocamlrun`	1m		
`interp.minibyte`	2m		
`interp.opt`	not built		
`stdlib.opt`	4h40m		
`ocamlc.opt`	25h40m		
Total	30h23m		

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Compilation times are large, but still good enough for reproducibility.

Performance analysis

Lots of inefficiencies that stack upon one another, so slowness is expected. Compilation times for `interp`:

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The cost of interpretation is far superior than the cost of naïve compilation.

Conclusion and future work

- Showed the absence of trusting trust attacks in OCaml 4.07.1.
- Takeaways for the design of OCaml: untyped semantics are good!
- Future work: target newer versions of OCaml.