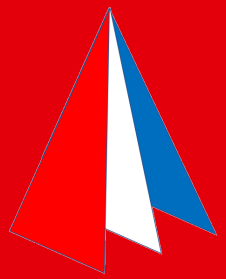
Quick Clean for the Web

Dante van Gemert

Thursday 5th February 2026



Radboud Universiteit

Web is where it’s at

E-mail, Google Docs, Typst, custom keyboard software, …

But: JavaScript 😬

Clean

Functional programming language

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iTasks

- Structure code with tasks
- Automagically generates web UI ✨

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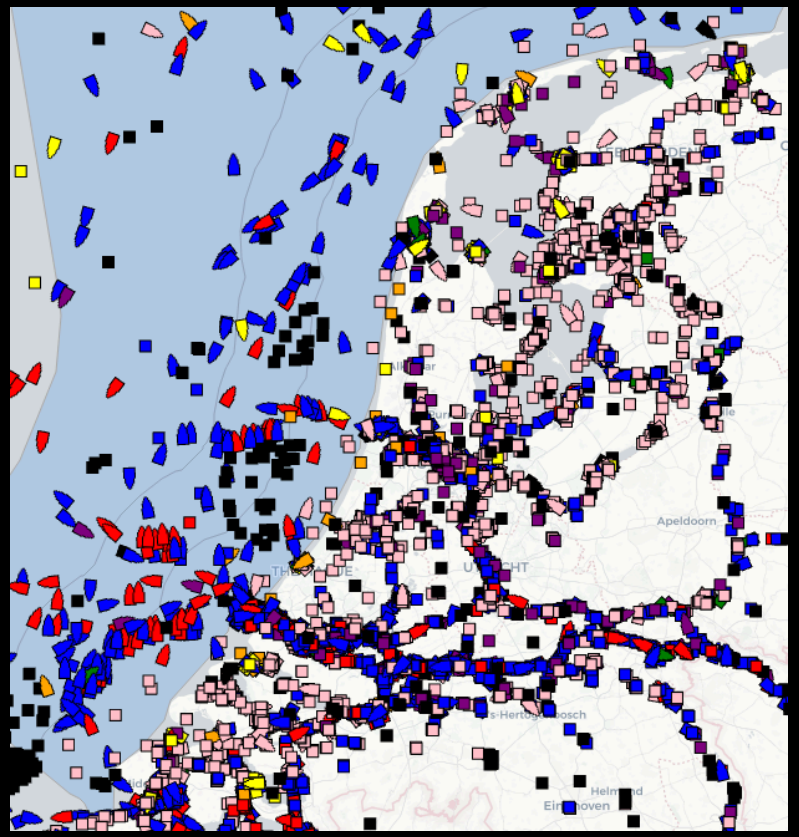
But: interpreting is too slow



VIIA

Clean-LLVM

Compile instead of interpret

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In short

- Clean web-app → iTasks
- Better performance → Clean-LLVM (instead of ABC interpreter)

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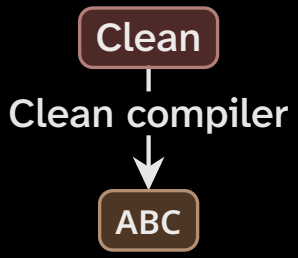
But: don’t want to compile Clean code directly

ABC

Use Clean compiler's ABC bytecode



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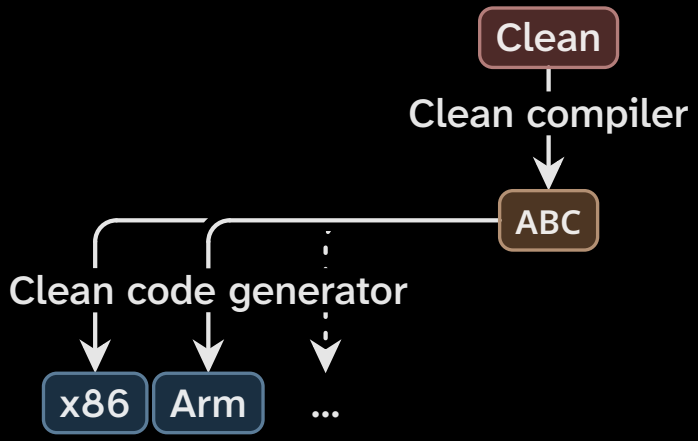

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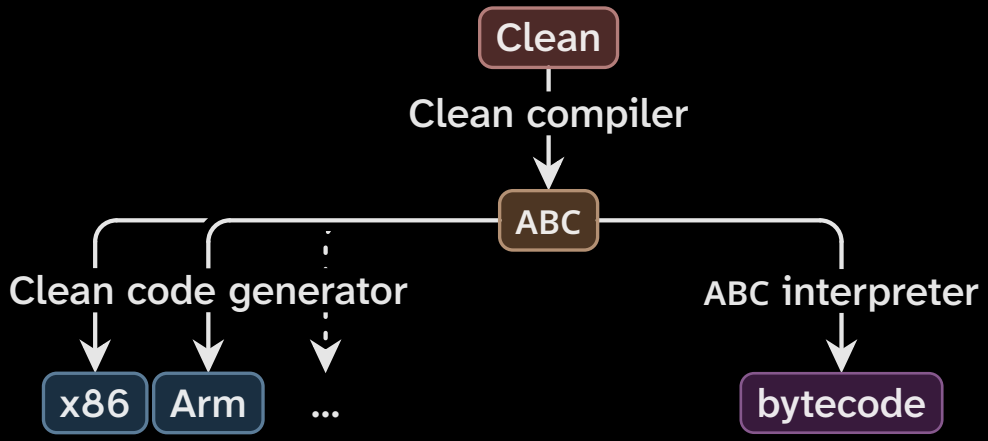

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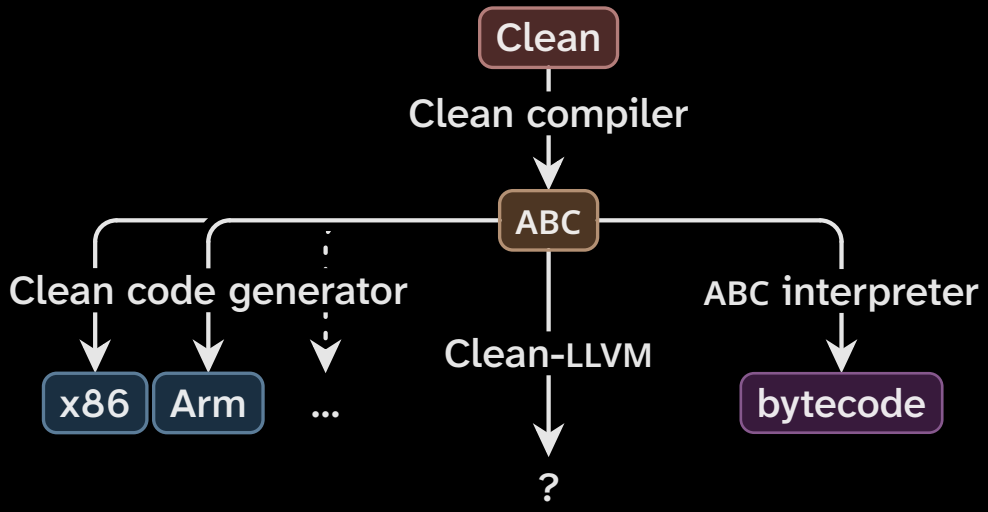

What do we compile **to**?

WebAssembly (Wasm)

Clean → ABC → ? → WebAssembly

- Compilation target for the web
- Stack based
- Safe & secure (→ restrictive)
- C(++), Rust, Go, Kotlin, Dart, …

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- Recently: tail calls

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But: we can do better than generating Wasm directly

LLVM

- Compiler toolkit
- Clang compiler for C & C++
- Intermediate representation (IR)
- Optimisation passes (inlining, dead code elimination, …)
- Rust, Zig, Julia, Swift, …

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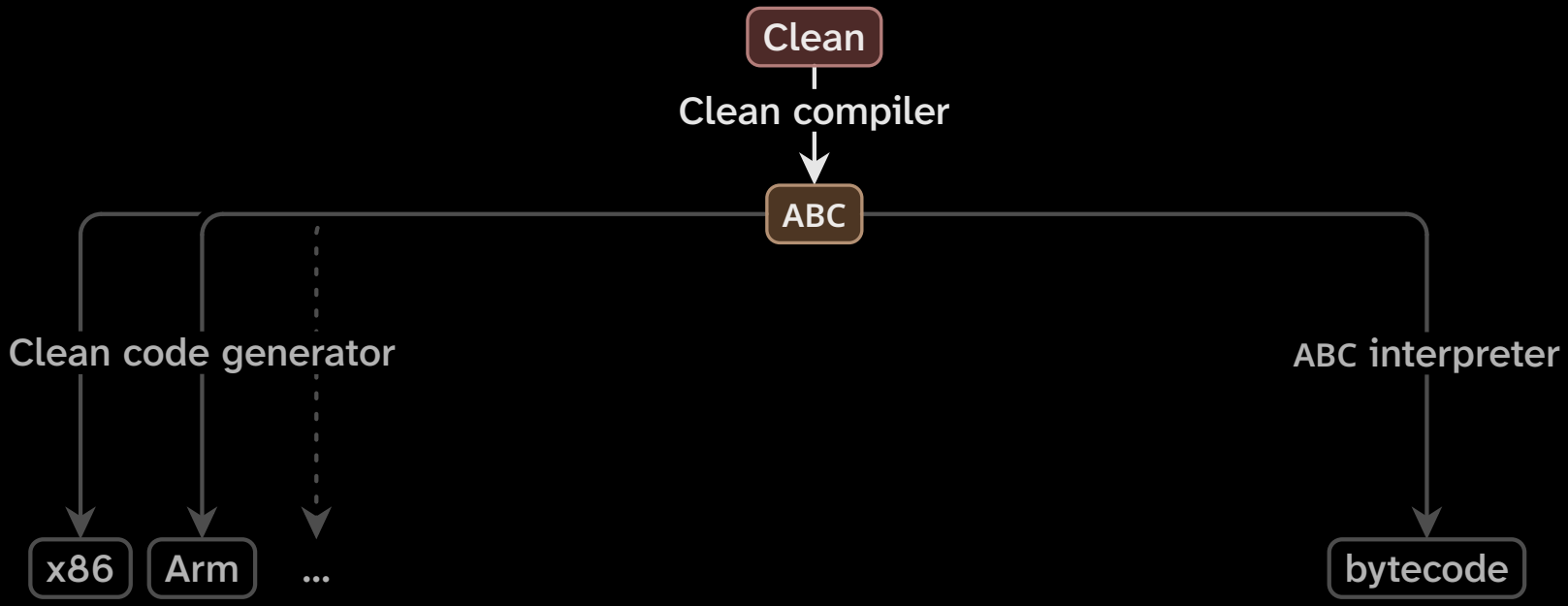
Wasm is not a standard target for LLVM

- Requires some creative solutions

Overview


Clean
Clean compiler
ABC
Clean code generator
ABC interpreter
x86
Arm
...
bytecode

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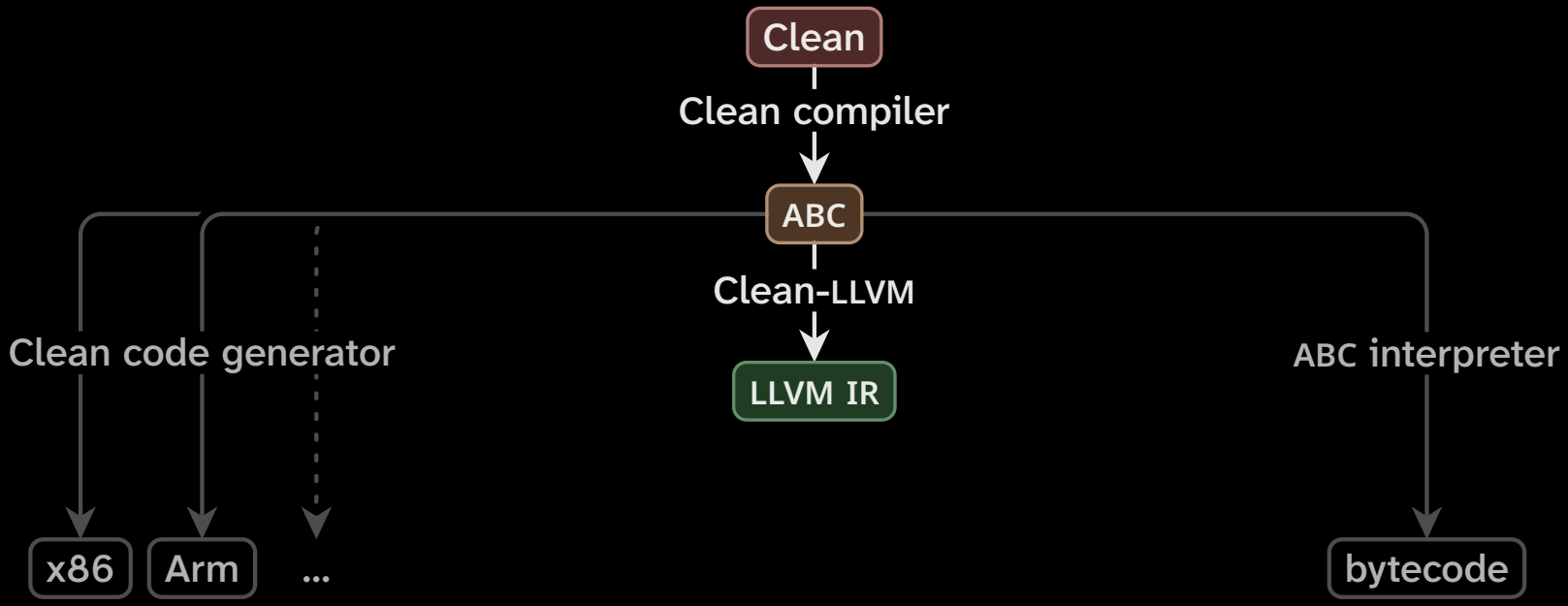
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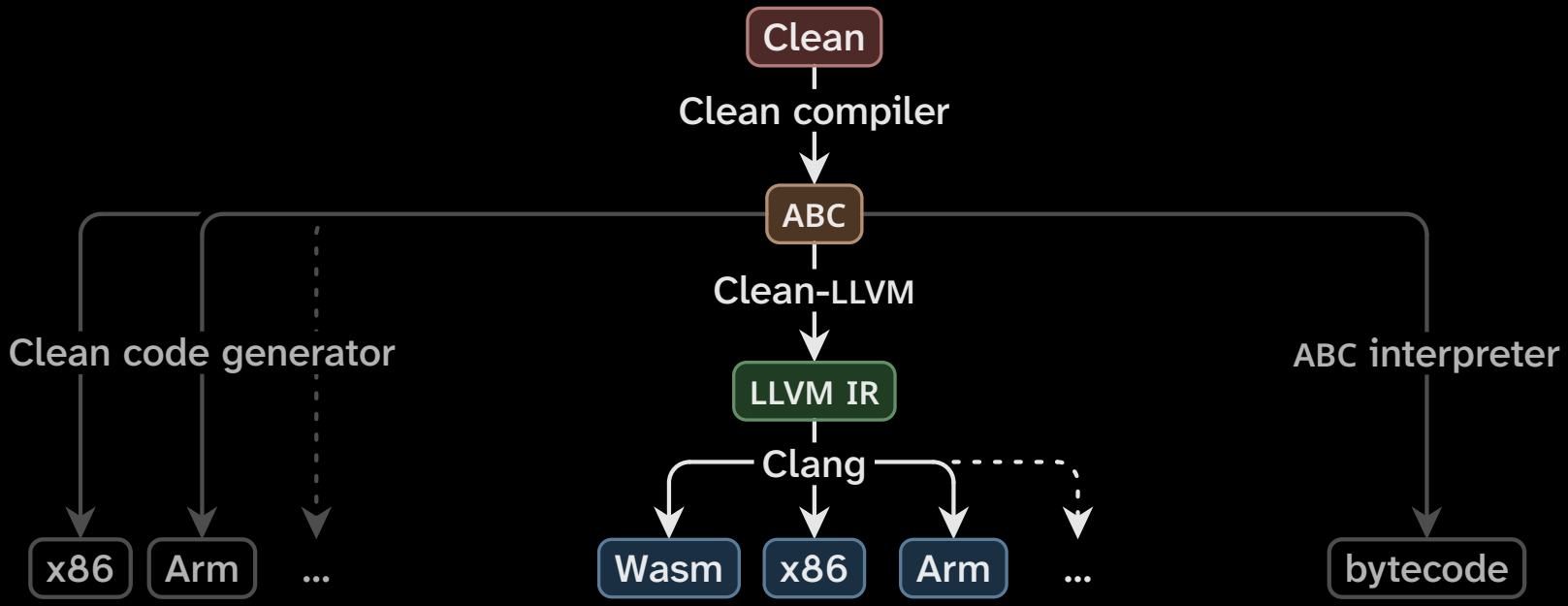
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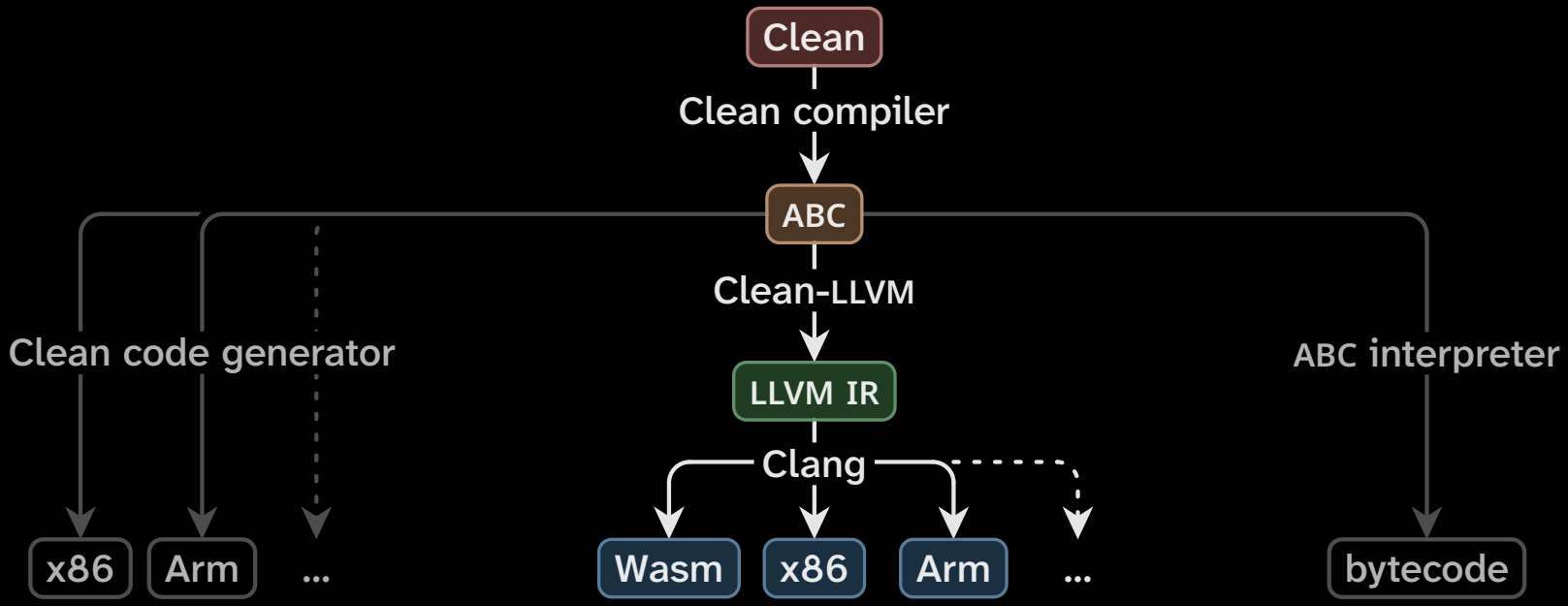


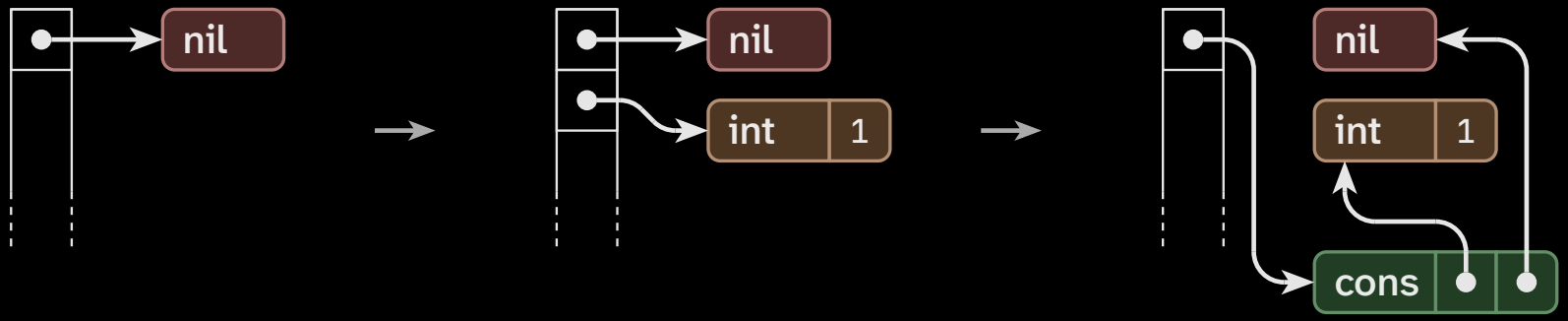
Focus on WebAssembly

GC Integration

Heap and A Stack

A stack: references to the heap (boxed values)
B stack: basic values (unboxed values: int, char, bool, ...)
C stack: control flow

(hence the name of ABC code)



Creation of the list `[1]`.

GC Integration

- A stack is on WebAssembly stack, for performance
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Shadow stack

1. **Spill** (write **A** stack to memory)
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Shadow stack

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LLVM passes

- Run optimisations before generating spills/restores: inlining, dead code elimination
- Leads to less function calls → less spill locations

Shadow Stack Overview

mark → statepoints → `asp` arg → spill

1. Mark A stack (preparation)
2. Insert statepoints
3. Add shadow stack argument
4. Add spills

Preparation: Mark A Stack

- Which LLVM variables are on **A** stack?
- Mark them with special type

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1. Mark heap references (**A** stack values)

```
ptr %a      →      heapptr %a
```

Note: simplified / imaginary syntax

LLVM Pass: Insert Statepoints

- Statepoint: point at which `GC` *can* run
- Only need to update spilled **A** stack across statepoints
  - spill before, restore after

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%a.new = call i64 @gc.relocate(%s, 0)
```

LLVM Pass: Add Stack Top Argument

3. Add argument for pointer to spilled **A** stack

- `asp` = **A S**tack **P**ointer

```
define i64 @f(i64 %x)
```

↓

```
define { ptr, i64 } @f_asp(ptr %asp, i64 %x)
```

LLVM Pass: Add Spills

4. Transform statepoints to function calls, spills, restores

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%s = call token @gc.statepoint(@f, 42) [ "gc-live"(heapptr %a) ]
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```
store %a to %asp ; spill
{ %asp.new, %answer } = call i64 @f_asp(%asp, 42)
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```
%a.new = load %asp.new ; restore
```

LLVM Passes: All Together

mark → statepoints → `asp` arg → spill

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Why statepoints?

Implementation for native x86 without shadow stack (theoretically)

Results

Benchmarks

Restriction: not all ABC instructions implemented yet

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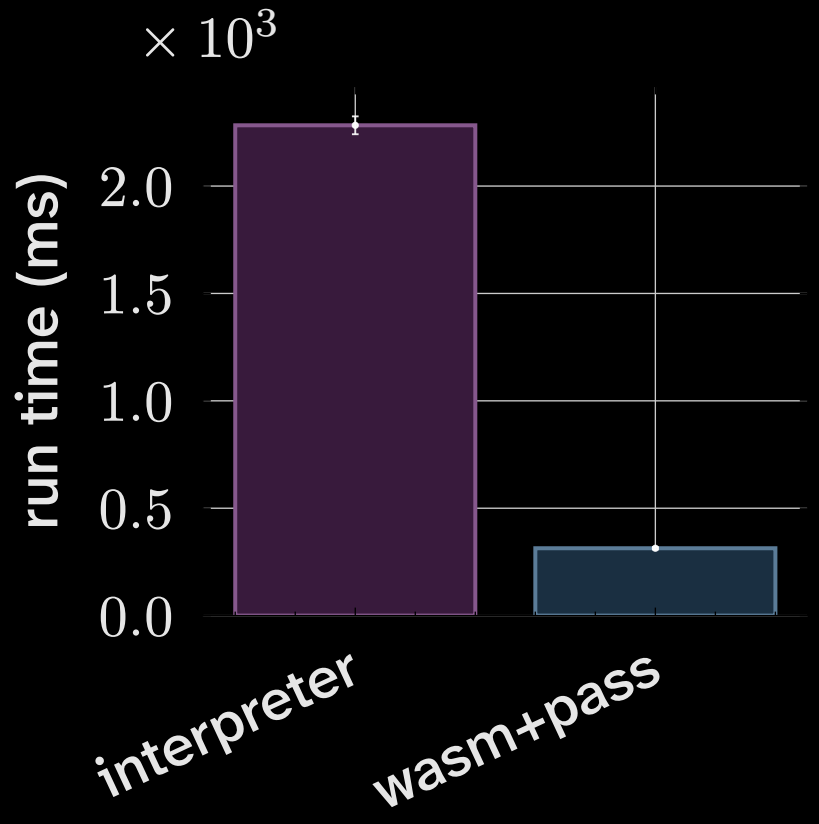
- List
  - Create a long list and sum it
- Astack
  - Create 16 heap nodes and pass them to multiple function calls
- **Binarytrees**
  - From the Computer Language Benchmark Game
  - Required additional ABC instructions

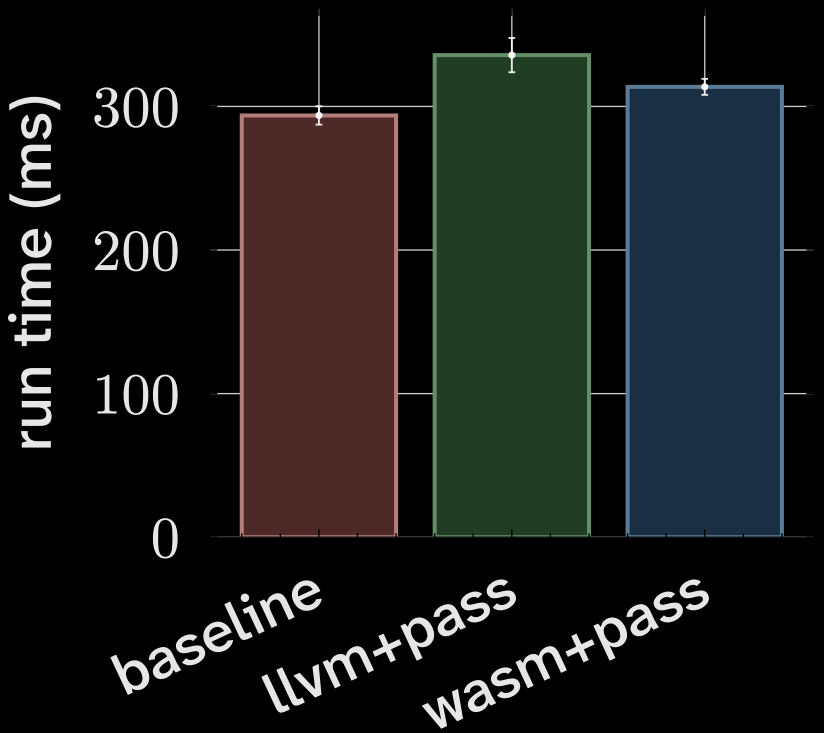
Benchmark: Binarytrees

Wasm: 7 times faster than ABC interpreter (2.3 s vs 0.3 s)



Benchmark: Binarytrees

Close to original Clean compiler's performance



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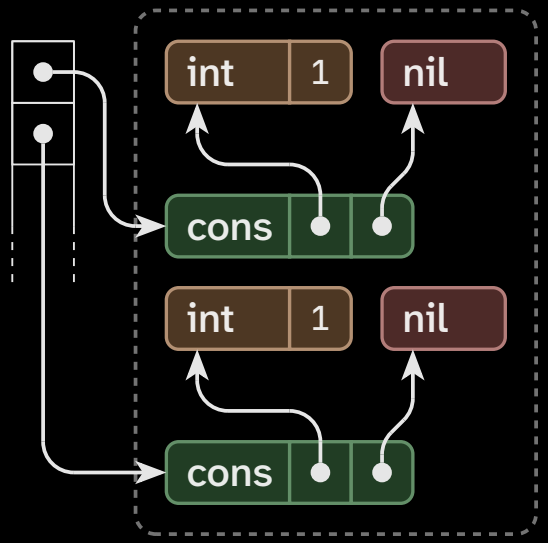
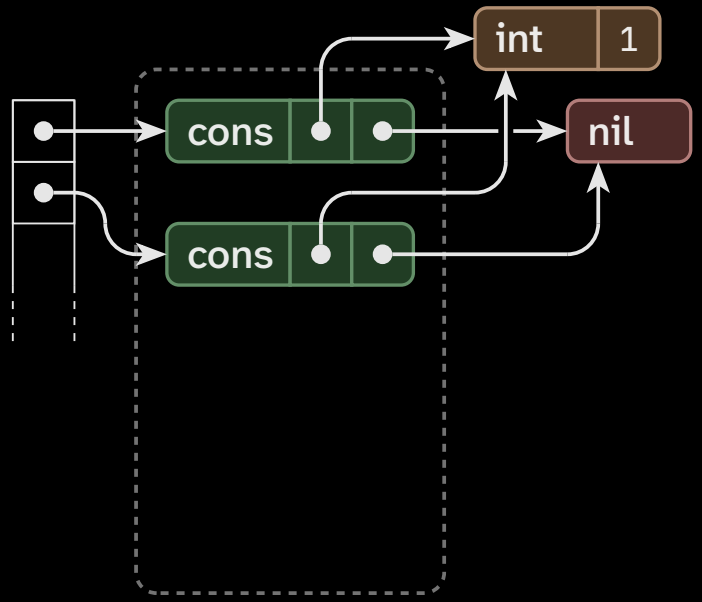
Future work: statepoints without shadow stack for native x86

Extra Slides

Optimisation: Static Nodes



without static nodes



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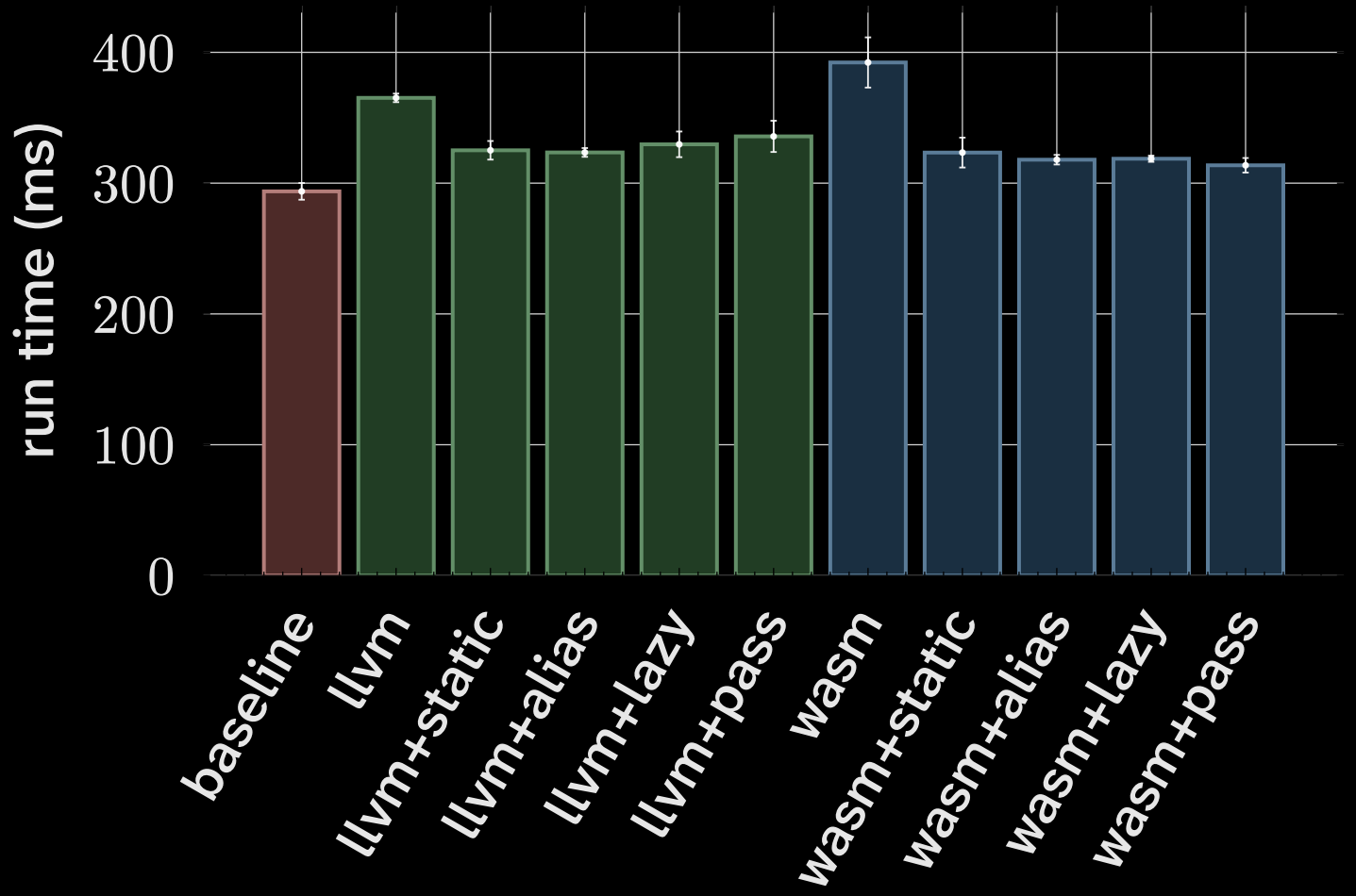
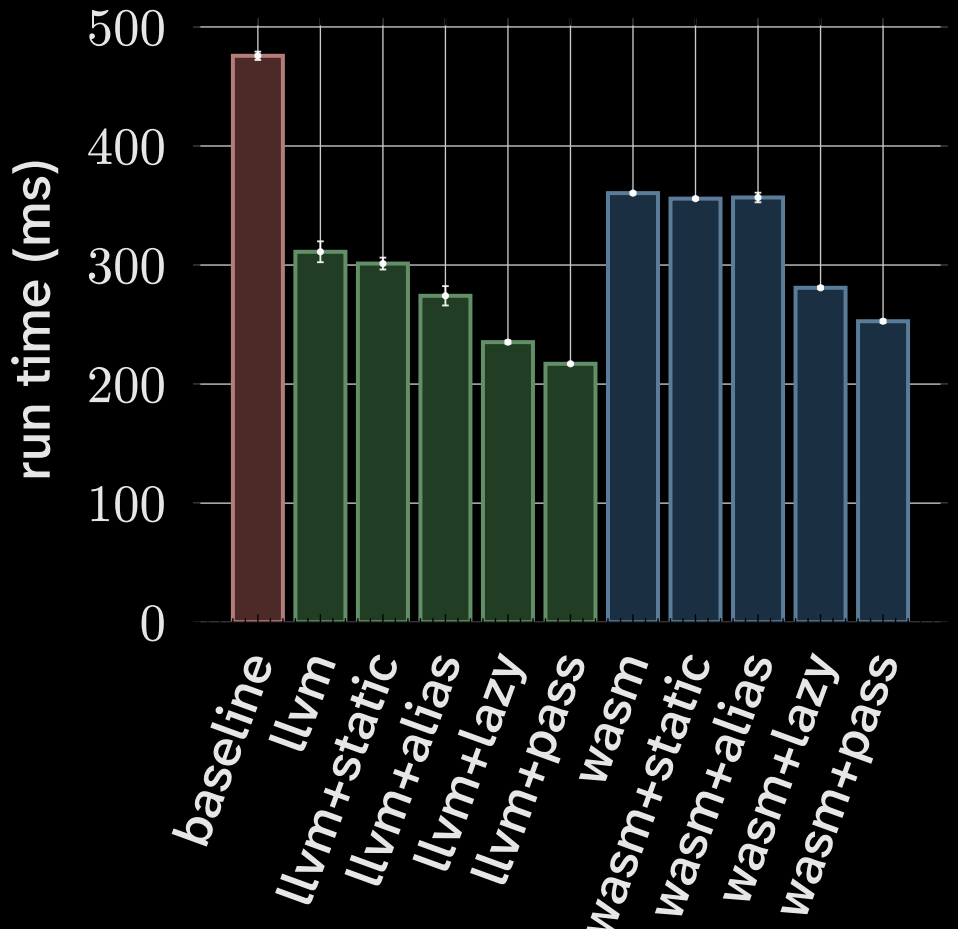
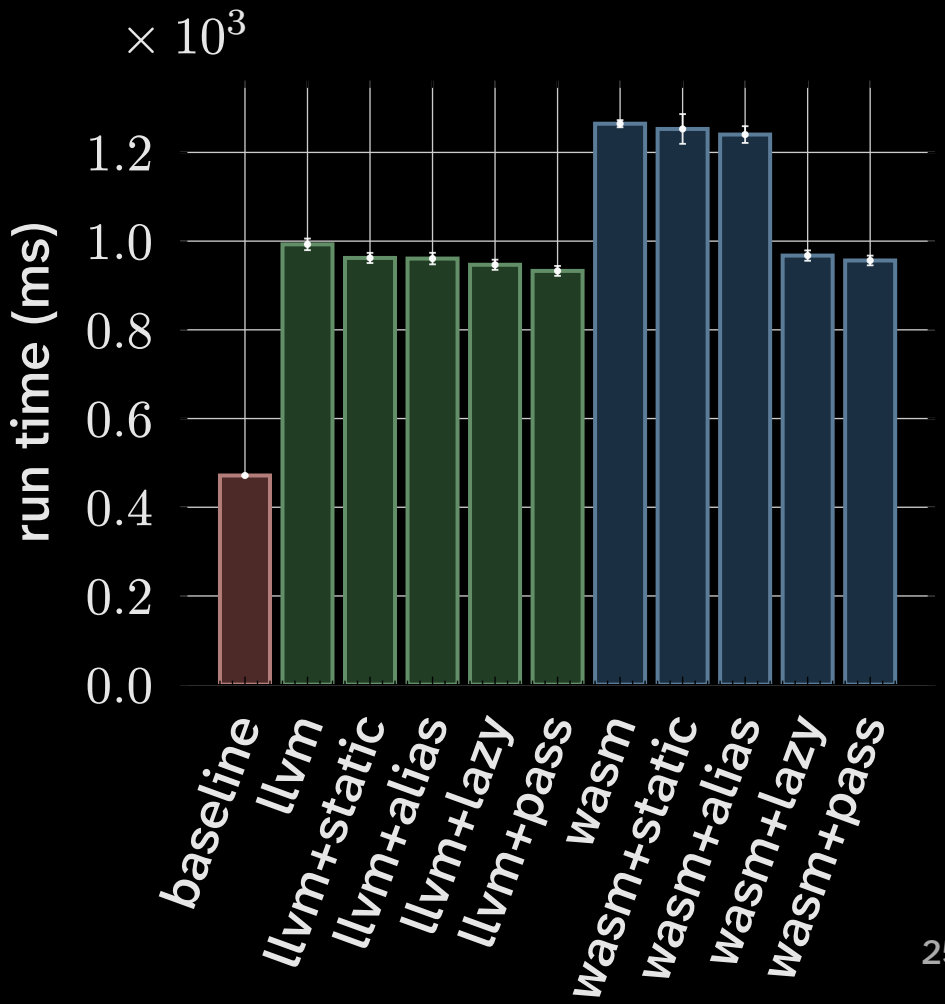
More Benchmarks: Binarytrees

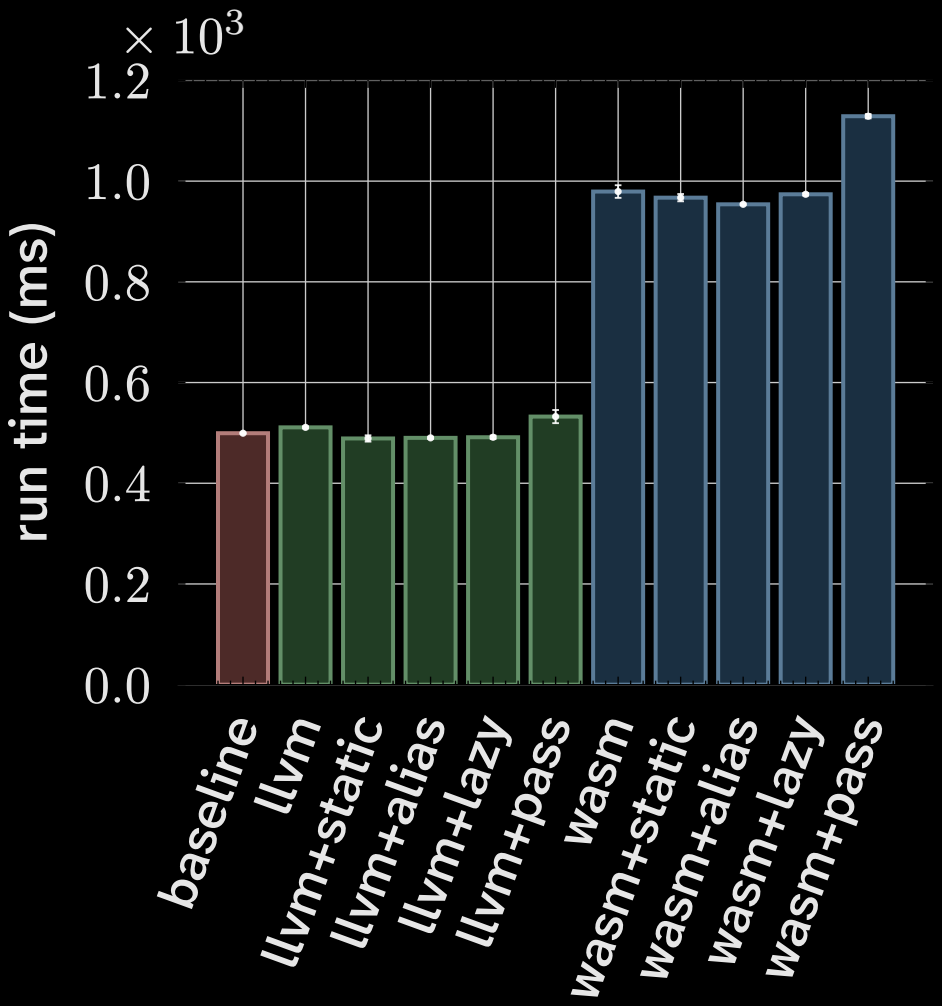


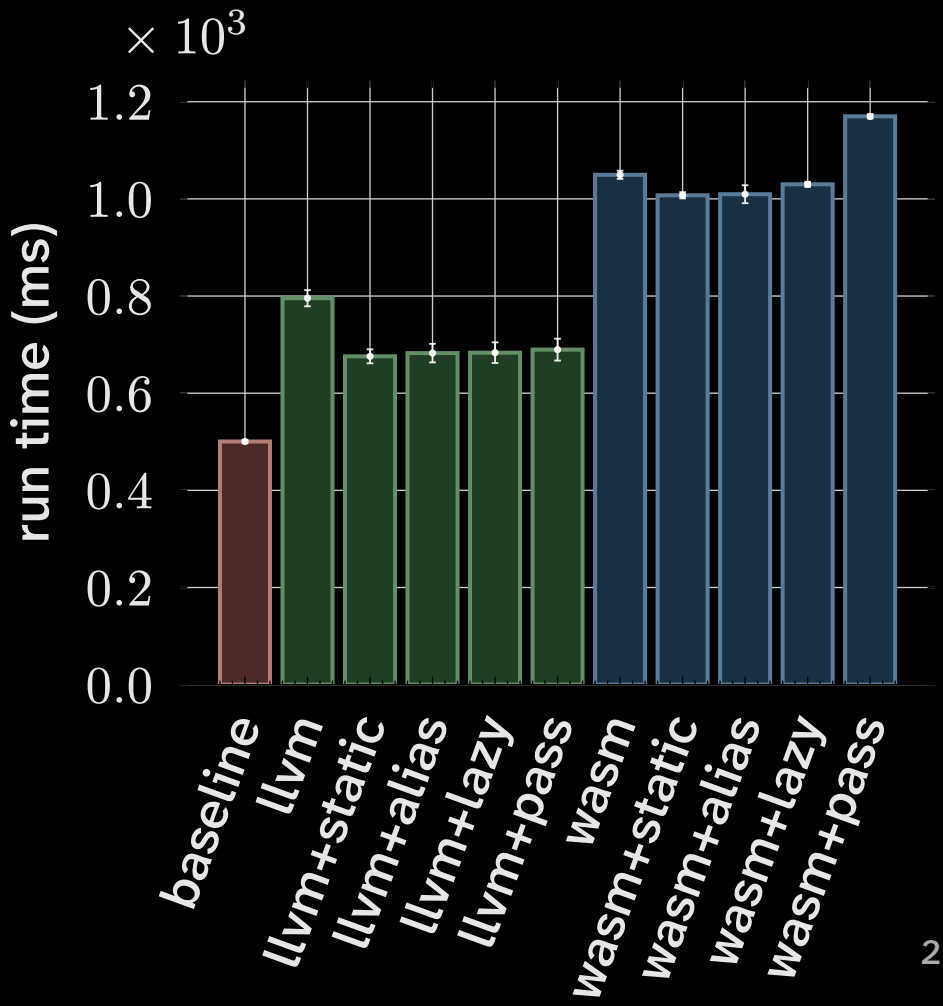
More Benchmarks: Astack





More Benchmarks: List





Questions

Why not Wasm GC?

- Not supported by LLVM (yet)
- Issues with Wasm's type safety when overwriting a thunk with its result