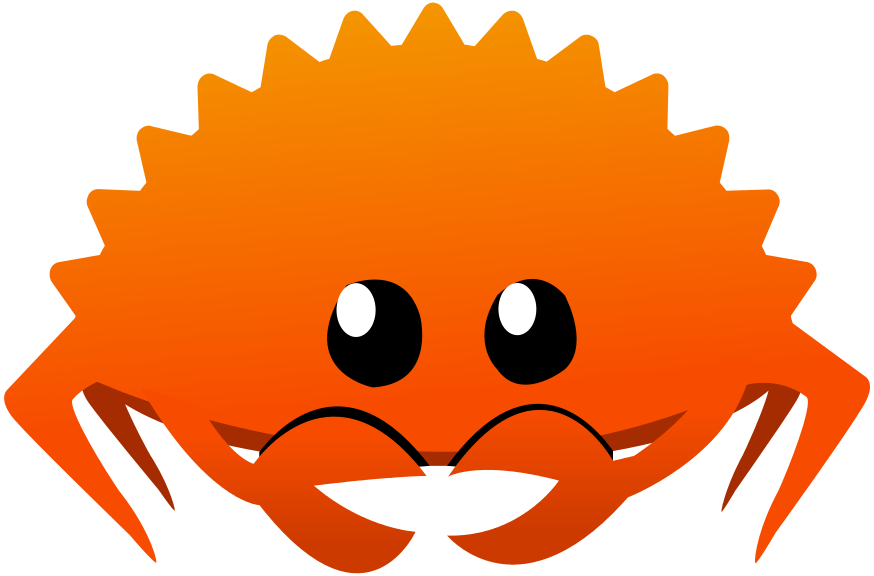
# Writing compilers in Rust?



Faith Ekstrand

XDC 2023

# About me

- Faith Ekstrand (@gfxstrand@mastodon.gamedev.place)
- First freedesktop.org commit: wayland/31511d0e, Jan 11, 2013
- Worked at Intel from June 2014 to December 2022
  - NIR, Intel (ANV) Vulkan driver, SPIR-V → NIR, ISL, other Intel bits
- Now at Collabora since January 2022
  - Work across the upstream Linux graphics stack, wherever needed
  - Currently the lead developer / maintainer of NVK

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# Introducing NAK: The Nvidia Awesome Kompiler

# NAK: The Nvidia Awesome Kompiler

- Brand new back-end compiler for NVIDIA hardware
- Written in Rust
- Tries to be a model NIR user
  - NIR passes are written in C
  - Lower in NIR, keep the back-end simple
- Fully SSA until register allocation
  - This register allocator actually works! 😂

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# Why Rust?

# Why Rust?

- C is kinda terrible. We all know this…
  - Those of us who prefer C know it best
- C++ is also terrible.
- Rust is less terrible?
  - Powerful type system that doesn’t rely on virtual dispatch
  - Has a large, well thought out standard library
  - Borrow checker that catches real bugs

# Wait, you don’t hate the borrow checker?!?

Nope! Once you learn to work with it, the borrow checker becomes a code review buddy, pointing out serious bugs.

Structuring your code to be borrow-checker-friendly often results in better, more obviously correct code.

# Why is NAK a good candidate for Rust?

- NAK is self-contained and doesn't need to call out
  - There are a few utilities we could maybe use
  - Mostly, it just consumes NIR and produces a blob of bytes
- The Rust/C interface for NAK is 7 functions
  - Not much to bindgen
- We only really need to *read* NIR
  - More on that...

# Can you write a compiler in it?

# But can you write a compiler in it?

- That’s the question I set out to answer with NAK.
- And… Yes, yes you can!
- You do need to make friends with the borrow checker…
  - Lots of hash maps
  - Lots of SoA where you might do AoS in C/C++

# Challenge 1: Reading NIR from Rust

- Not too bad if the Rust NIR usage is read-only
- NIR lowering passes and optimization loop are written in C
- Rust NIR wrappers take a `&nir_shader` (not `mut`!)
  - Uses traits to add methods to NIR types
  - You can do `nb.iter_instrs()` on a `&nir_block`
  - Iterator for `exec_list` (thanks, Karol)
  - `srcs_as_slice()` allows safe `srcs[]` array access
  - `NirSrc::as_uint() -> Option<u64>` gets a `u64` if a source is const

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# Challenge 2: Instruction sources

There are a lot of things we want:

- Clear meaning of sources
  - inst.src[3] doesn't really mean anything.
  - This gets worse when there are indirects
- Fast, generic access to sources
  - Passes like copy propagation don't care what most sources mean
- Avoid extra array allocations
- Special sources like predicates and indirects
- Source modifiers (because, of course there are…)

# Prior art: NIR

- Sources are in arrays
- Depend on documentation to know what's what
  - We all know just how well that works…
- We avoid extra allocation by using unsized arrays
  - Rust can't do that!
- Everything is an SSA def or const_index
  - No modifiers
  - No types
- We depend on nir_validate to ensure correctness

# Prior art: ACO

- Each instruction is its own type
  - This helps a bit with metadata like rounding modes
- Sources are still arrays
  - Each instruction documents source meanings
- Avoid extra allocation using aco::span<T>
  - Basically, it's unsized arrays except way better and you can have more than one
  - O(1) source access
  - Supports all the usual C++ iterator stuff
  - Can have large numbers of sources AND destinations
  - Not implementable in Rust…

# How to do this in Rust...

If I could have everything I want....

- Want to use Rust enums...
  - Rust enums are tagged unions
  - Safer than NIR's enum and pointer cast
- Want descriptive names for sources
- Want typesafe metadata
- Want Rust's type system to check stuff for me
- Want generic O(1) access to sources

# You can't always get what you want

# But if you try sometimes, well, you just might find You get what you need…

# Let’s look at some NAK code….

```rust
#[repr(C)]
#[derive(SrcsAsSlice, DstsAsSlice)]
pub struct OpSel {
    pub dst: Dst,

    #[src_type(Pred)]
    pub cond: Src,

    #[src_type(ALU)]
    pub srcs: [Src; 2],
}
```

# Let's look at some NAK code....

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Named Destination

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**Named Sources**

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Type Decorations

# Let’s look at some NAK code....

```
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    pub dst: Dst,

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    pub cond: Src,

    #[src_type(ALU)]
    pub srcs: [Src; 2],
}
```

Magic

# Let’s look at some NAK code....

```rust
pub trait SrcsAsSlice {
    fn srcs_as_slice(&self) -> &[Src];
    fn srcs_as_mut_slice(&mut self) -> &mut [Src];
    fn src_types(&self) -> SrcTypeList;
}

pub trait DstsAsSlice {
    fn dsts_as_slice(&self) -> &[Dst];
    fn dsts_as_mut_slice(&mut self) -> &mut [Dst];
}
```

# Let’s look at some NAK code....

```
#[derive(Display, DstsAsSlice, SrcsAsSlice,
pub enum Op {
    FAdd(OpFAdd),
    FFma(OpFFma),
    FMnMx(OpFMnMx),
    FMul(OpFMul),
    MuFu(OpMuFu),
    FSet(OpFSet),
    FSetP(OpFSetP),
    FSwzAdd(OpFSwzAdd),
    DAdd(OpDAdd),
```

Even more magic!

# Let's look at some NAK code....

```
if self.is_instr_live(instr) {
    if let PredRef::SSA(ssa) = &instr.pred.pred_ref {
        self.mark_ssa_live(ssa);
    }

    for src in instr.srcs() {
        self.mark_src_live(src);
    }
} else {
    self.any_dead = true;
}
```

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# This gets us most of what we want

- Good use of Rust enums
- Descriptive names for sources
- Typesafe metadata
- ~~Rust's type system to check stuff for me~~
- Generic O(1) access to sources

- Works with all Rust's iterator stuff
- Only per-op code is a lookup table

# Let’s look at some NAK code....

```
#[repr(C)]
#[derive(SrcsAsSlice, DstsAsSlice)]
pub struct OpFAdd {
    pub dst: Dst,

    #[src_type(F32)]
    pub srcs: [Src; 2],

    pub saturate: bool,
    pub rnd_mode: FRndMode,
}
```

We can do metadata, too

# Challenge 3: Representing values

There are a lot of things we want:

- SSA and registers
  - We need registers for final code-gen
- Vectors and 64-bit values
  - This one has hidden and very subtle SSA-based RA implications
- Predicates and GPRs
- Uniform and non-uniform values
- Immediates and cbufs

# SSA Values

- Each `SSAValue` represents a single 32-bit value
  - Has a `RegFile` (GPR, Pred, UGPR or UPred), and 29-bit index
  - Packs into 32 bits so it's cheap to copy around
  - Implements `Eq+Hash` so it can be a `HashMap` key
- Each `SSARef` contains 1-4 `SSAValues`
  - Packs into 128 bits so it's cheap(ish)
  - Implements `Deref<[SSAValue]>`
- Register allocation automatically collects into consecutive register ranges as-needed

# Other value types

- A `RegRef` represents a register range
  - Has a `RegFile`, an index, and a number of components.
- A `CBufRef` represents a constant buffer value
  - 32 or 64 bits, depending on opcode
- An `Imm32` represents a 32-bit immediate
  - Or the top 32 bits of a 64-bit source
- Special case immediates: `Zero`, `True`, and `False`
  - Often allowed when Imm32 is not

# Sources and Destinations

```
#[derive(Clone, Copy, Eq,
pub enum SrcRef {
    Zero,
    True,
    False,
    Imm32(u32),
    CBuf(CBufRef),
    SSA(SSARef),
    Reg(RegRef),
}
```

```
#[derive(Clone, Copy)]
pub enum Dst {
    None,
    SSA(SSARef),
    Reg(RegRef),
}
```

# Challenge 4: Instruction lists

- NIR uses linked lists of instructions
  - O(1) insertion, intrusive so no extra allocation, they're great!
  - Rust really doesn't like linked lists…
- Proper container types are essential to Rust's safety model
- We use `Vec<Box<Instr>>`
  - Everything is safe. Yay!
  - You can't insert in the middle. Booo…
- The biggest challenge is mutability
  - You can't look at one element while modifying another (at least not easily)

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# Mutability challenges

`Vec<T>` doesn’t let you have mutable references to multiple elements simultaneously.

There are a few workarounds:

- `slice::split_at_mut()` to split the slice
- Use indices like you would pointers and `v[i]` everywhere
  - This gets sketchy fast!
- Re-structure your pass to avoid mutability

# A safe pattern: Map

- `map_instrs()` takes a callback mapping an instruction to zero or more instructions.
- Provided by Shader, Function, and BasicBlock
- Most simple optimization or lowering passes use `map_instrs()` to avoid mutability headaches

# A safe pattern: Map

```rust
pub fn lower_vec_split(&mut self) {
    self.map_instrs(|instr: Box<Instr>, _| -> MappedInstrs {
        match instr.op {
            Op::INeg(neg) => MappedInstrs::One(Instr::new_boxed(OpIAdd3 {
                dst: neg.dst,
                srcs: [Src::new_zero(), neg.src.ineg(), Src::new_zero()],
            })),
            _ => MappedInstrs::One(instr),
        }
    })
}
```

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# More complicated passes hand-roll…

```
let mut instrs = Vec::new();
for (ip, mut instr) in bb.instrs.drain(..).enumerate() {
    match &mut instr.op {
```

```
        instrs.push(instr);
}
bb.instrs = instrs;
```

It’s not ideal but it works

# The gather/modify pattern

Most passes happen in two separate steps:

- Step 1: Gather information about SSA values
- Step 2: Transform the IR based on the gathered information

- This keeps Rust's borrow checker happy...
- And it prevents bugs!
  - Lots of NIR bugs have crept in because of accidentally looking at the IR you've already modified and assuming it's the original.

# Working with SSA values

- `HashMap` is your friend…
  - Gather pass builds a `HashMap<SSAValue,Data>`
  - Modify pass uses the map to update instructions
- Examples:
  - Dead code builds a `HashSet<SSAValue>` of live SSA values
  - Copy prop builds a `HashMap<SSAValue,Copy>` of copies

# Challenge 5: Control-flow graphs

- Graphs are a PITA with Rust
  - You inevitably end up with tables and indices
- Hide all the insanity!
- `CFG<T>` is a generic container type
  - NAK uses `CFG<BasicBlock>` but you can use any type
  - Stores nodes and edges (each nodes has `&[usize]` preds and succs)
  - Contains dominance and loop nesting information
  - Re-orders by reverse post-order DFS
  - Implements `Deref<[T]>` so you can iterate it

# Challenge ∞: Spilling and RA

Yeah... This presentation is already long enough. 😅

# Final thoughts: Do I like it?

Yes! I've loved working on NAK in Rust

- Rust enums (tagged unions) are awesome
- Proc macros are tricky but really useful
- Rust's traits and generics work well
- I like having a standard library
- Over-all, abstractions are just as powerful but more explicit in Rust than with C++

# Final thoughts: Advice for others

- `HashMap<K, V>` is your friend
- Implement `From<T>` for everything
- The borrow checker is your friend, not your enemy
  - Re-structure your code to be borrow-checker friendly
  - Don’t just Rc everything. Interior mutability isn’t as cool as it looks

# Thank you!

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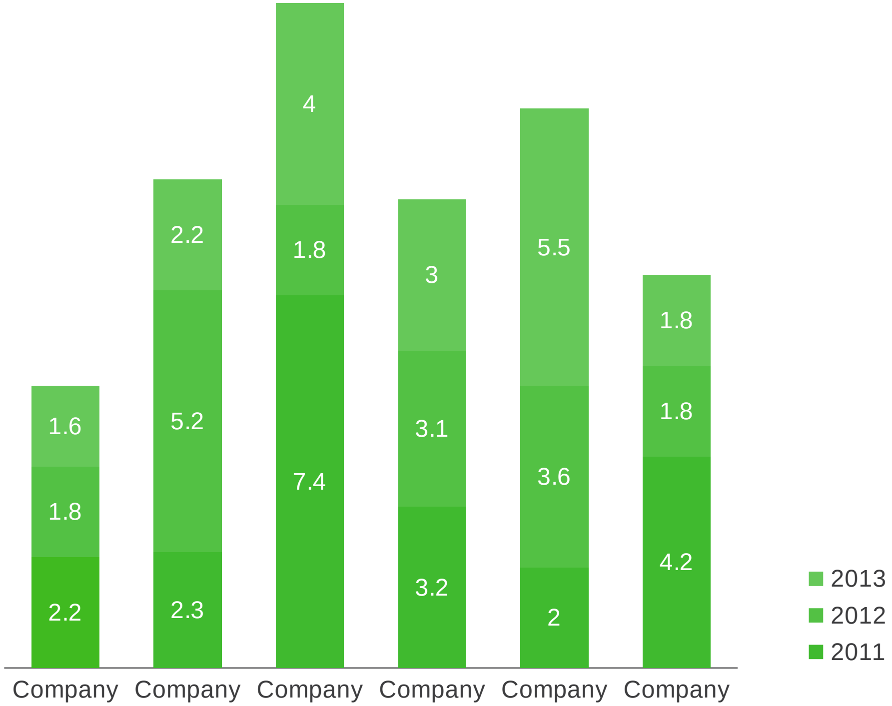


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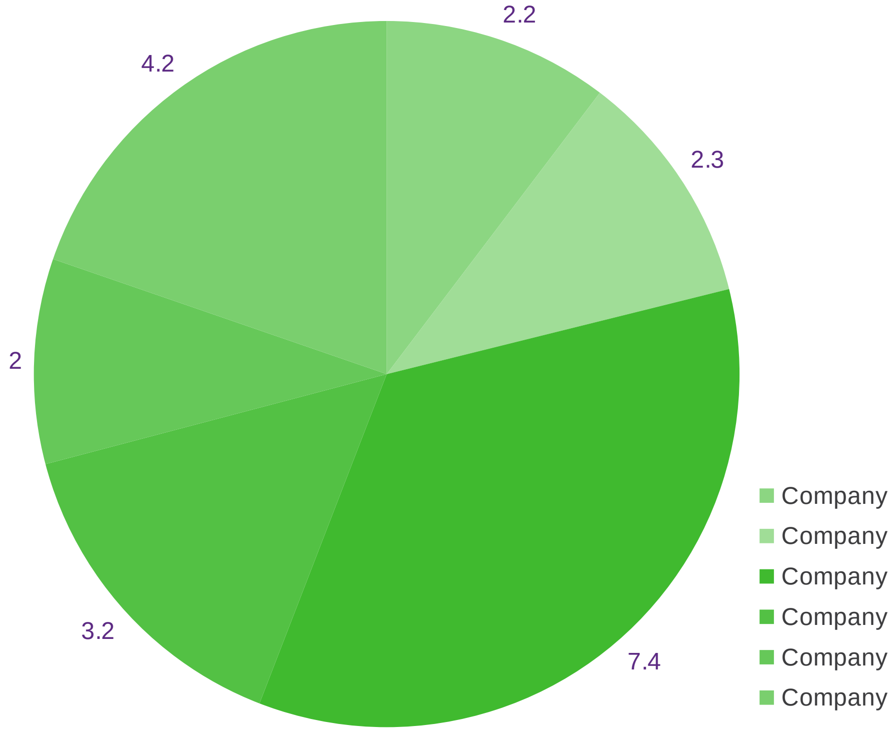


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