Pattern-matching with mutable state: danger!

Thomas Refis, Nick Roberts, **Gabriel Scherer**

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Danger!

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type 'a option = None | Some of 'a
type u = {a: bool; mutable b: int option}

let f (x : u) =   (* example by Stephen Dolan, 2017 *)
  match x with
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Recipe:

- patterns that look into mutable fields
- ability to evaluate code concurrently
  (**when** guards, allocations, data races)
- optimizing pattern compiler

In this talk

1. Automata/Backtracking/Split-based pattern-matching compilation
2. Optimizations in OCaml
3. Relaxing optimizations for mutable state

Section 1

Automata/Backtracking/Split-based pattern-matching compilation

Pattern-matching compilation

General case: n-ary pattern matrices.

$$
\begin{array}{l}
\texttt{match}\ \langle a_1 \ldots a_n \rangle\ \texttt{with} \\
\mid\ \langle p_1 \ldots p_n \rangle\ \rightarrow\ e_1 \\
\mid\ \langle q_1 \ldots q_n \rangle\ \rightarrow\ e_2 \\
\mid\ \ldots \\
\mid\ \langle r_1 \ldots r_n \rangle\ \rightarrow\ e_m
\end{array}
$$

Pattern-matching compilation

Naive idea: consider all possible constructors for a_1.

```
match ⟨l v⟩ with
| ⟨[] p⟩ → foo
| ⟨_  q⟩ → bar
| ⟨[] r⟩ → bim
```

$\Longrightarrow$

```
switch l with
  | [] →
    match v with
    | p → foo
    | q → bar
    | r → bim
  | _::_ →
    match v with
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Problem: the clause `q → bar` is duplicated.

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EXPONENTIAL!

Avoiding code blowup: two approaches

Split-based algorithms (automata/backtracking):

linear code size, but repeated check

Decision trees:

hashconsing strategies to avoid code size blowup

OCaml is split-based. (So are SML implementations; historically first)

Split-based algorithms

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$\Longrightarrow$

```
try
1: match ⟨l v⟩ with
   | ⟨[] p⟩ → foo
   | _ → fail
2: match ⟨l v⟩ with
   | ⟨_  q⟩ → bar
   | _ → fail
3: match ⟨l v⟩ with
   | ⟨[] r⟩ → bim
   | _ → fail
4: raise Match_failure
```

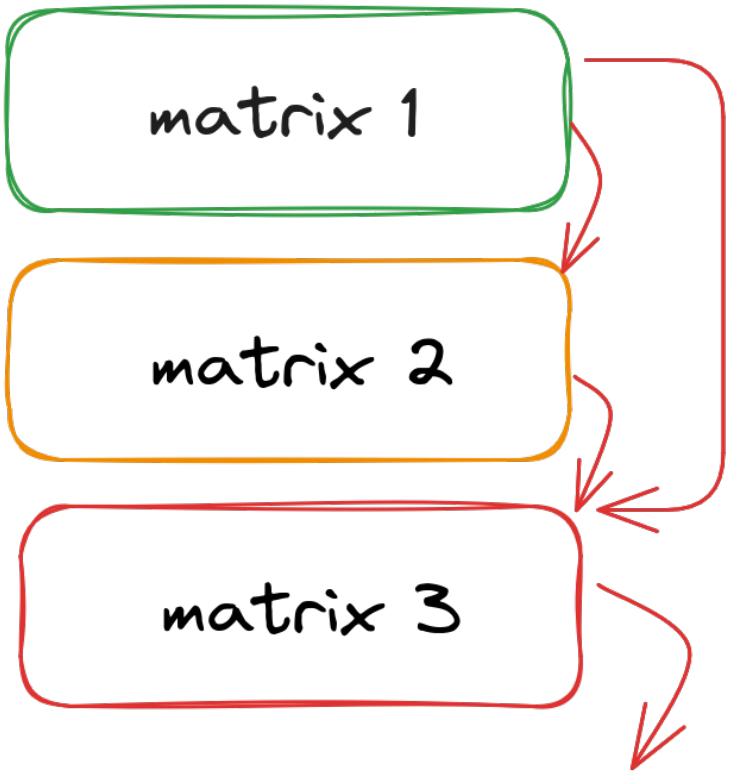
After splitting, each inner match can be compiled to a switch without duplication. `fail` jumps to the next submatrix.

Pros: linear code size.
Cons: some checks (here `[]`) are repeated.

Section 2

Optimizations in OCaml

Static information



- context:
  static knowledge on matched values
- jump summary:
  the context of each jump
  $\Longrightarrow$ optimizes jump targets
- default environment:
  the matrix of each jump target
  $\Longrightarrow$ optimize jumps
- totality
  $\Longrightarrow$ optimize the last matrix

```
compile: totality * env * context * source-matrix
      → compiled-matrix * summary
```

Contexts

```
switch p with
| false → ...
| true →
  switch l with
  | [] → ...
  | x::xs →
    (* HERE *) ...
```

- context at `(* HERE *)`:

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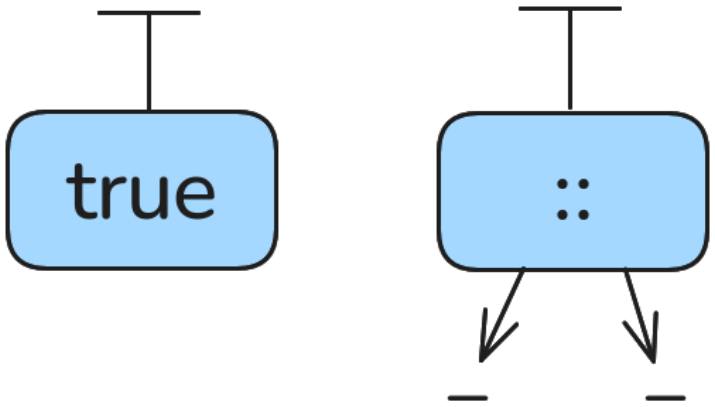

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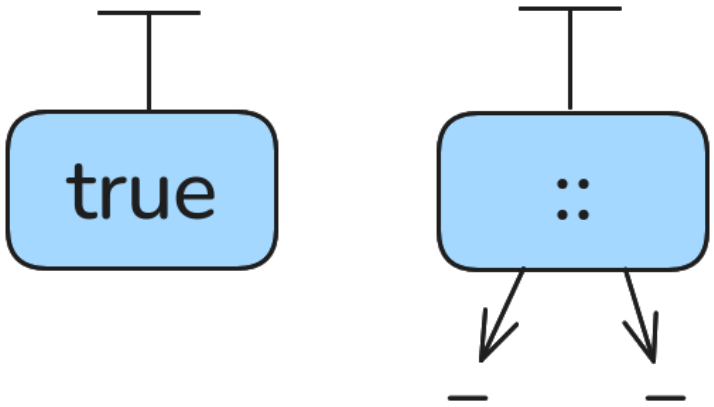

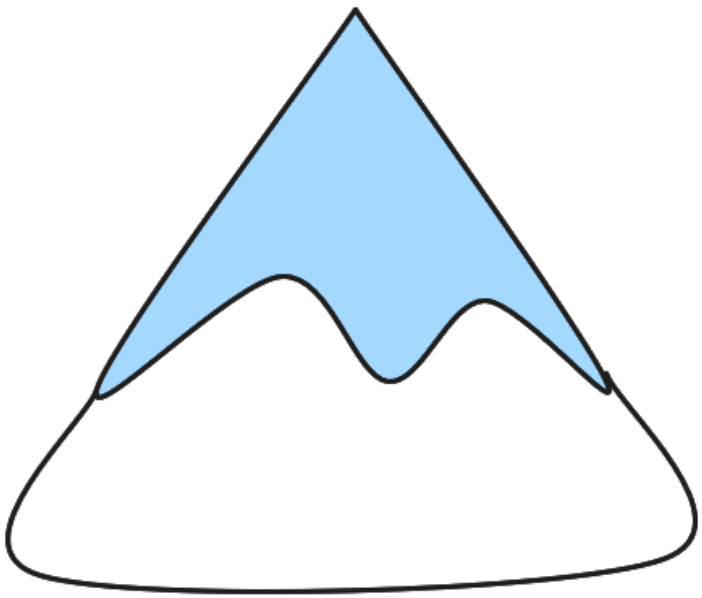

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Totality

```
match ⟨l ...⟩ with
| ⟨x::xs ...⟩ → foo
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(notice: no | _ → fail case)

Direct field access.

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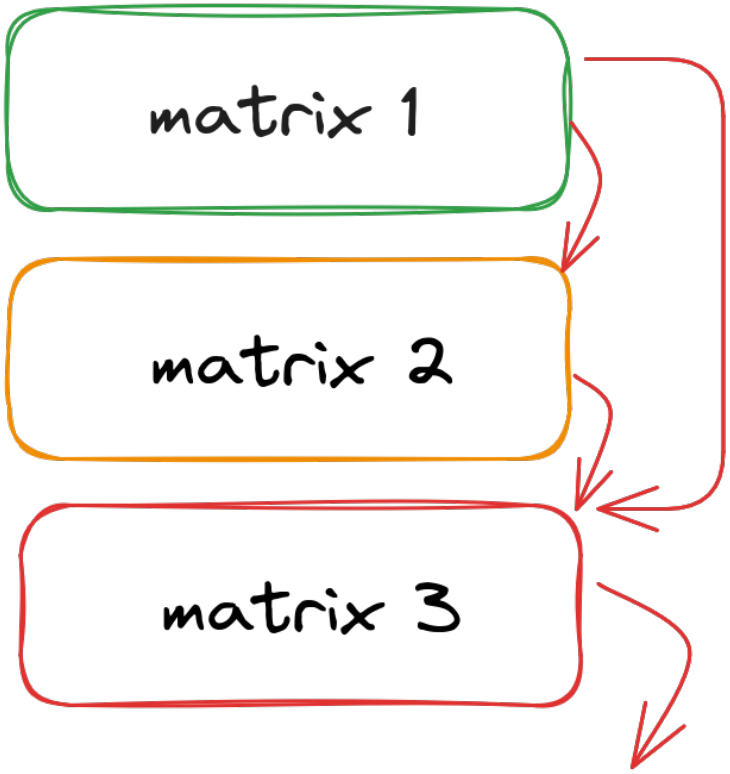
Awkward design in OCaml:

- type-checker computes totality information (and checks exhaustivity, usefulness, etc.)
- compiler does not use type information

Big picture (again)



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Section 3

Relaxing optimizations for mutable state

Bug (reminder)

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```

Bug 1: incorrect contexts

```
try
1: match x with
  | {a = false; b = _} → 0
  | {a = _;    b = None} → 1
  | _ → fail (* HERE *)

2: match x with
   | _ →
     if (x.b <- None; false) then 2
     else fail (* ALSO HERE *)

3: match x with
  | {a = true; b = Some y} → y
```

Context on both `fail`:

$\langle$`a = true; b = Some _`$\rangle$

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Not just about **`when`**.

At the point of `fail`, *any* concurrent mutation can invalidate the context.

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Context on `fail`:

$\langle$`a = true; b = Some _`$\rangle$

Not just about **`when`**.
At the point of `fail`, *any* concurrent mutation can invalidate the context.

Solution: erase context information in mutable positions.

below: $\langle$`a = true; b = _`$\rangle$

Safe!

Bug 2: incorrect totality

```
3: match x with
  | {a = true; b = Some y} → y
```

Notice that there is no `| _ → fail` at the end. Wrong!

Problem: the type-checker believes this program to be total.

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```

Fix 1: forget about totality

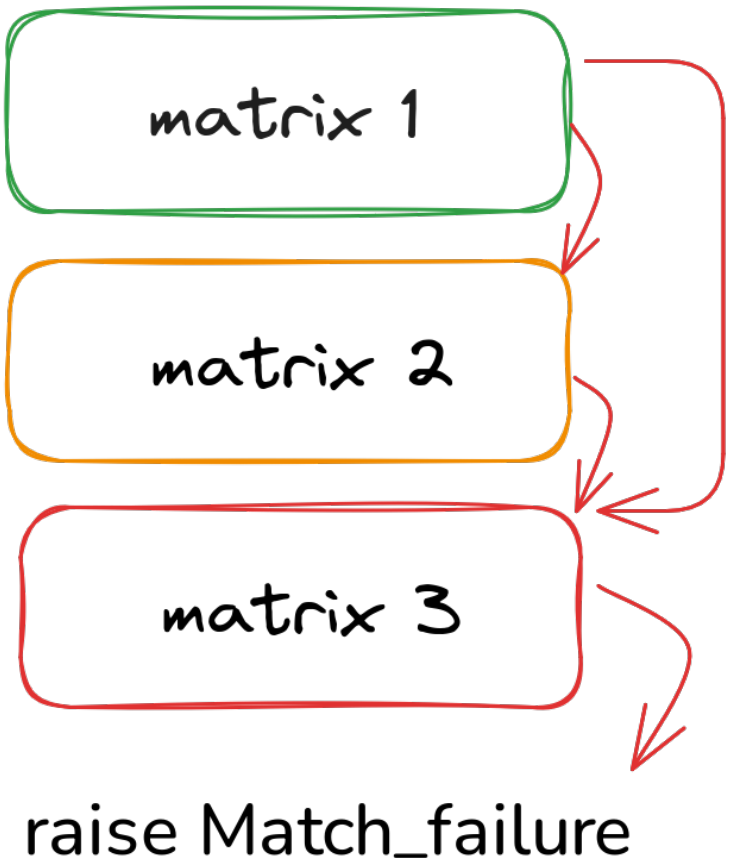
Fix: do not trust the type-checker, only the match compiler;
(it can sometimes prove totality)

Problem: many programs are pessimized by this criterion,
notably all GADT matches.

Fix 2: forget totality in mutable posititions

Only pessimize matches under a mutable field (transitively).

Fix 3: temporality heuristic




```
type temporality =
  First | Following
```

Totality can optimize matrix 3
(outside mutable positions)

Temporality can de-pessimize matrix 1
(at mutable positions)

If the user matching has no split: no pessimization.

Impact analysis

We believe that there were *no* unsound matchings
in real-life OCaml programs.

... but the fix pessimizes more programs

How can we convince everyone to pay the cost of correctness?

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We believe that there were *no* unsound matchings
in real-life OCaml programs.

... but the fix pessimizes more programs

How can we convince everyone to pay the cost of correctness?

1. We implemented a warning to detect pessimization.
2. Nick Roberts compiled the Jane Street codebase with it:

   I've tested this change and found indeed that it flags only complex matches on mutable fields — I found only 3 instances in a codebase with millions of lines, and it was possible to rewrite them without much trouble.

Thanks!

Questions?