MPark.Patterns

Pattern Matching in C++

https://github.com/mpark/patterns

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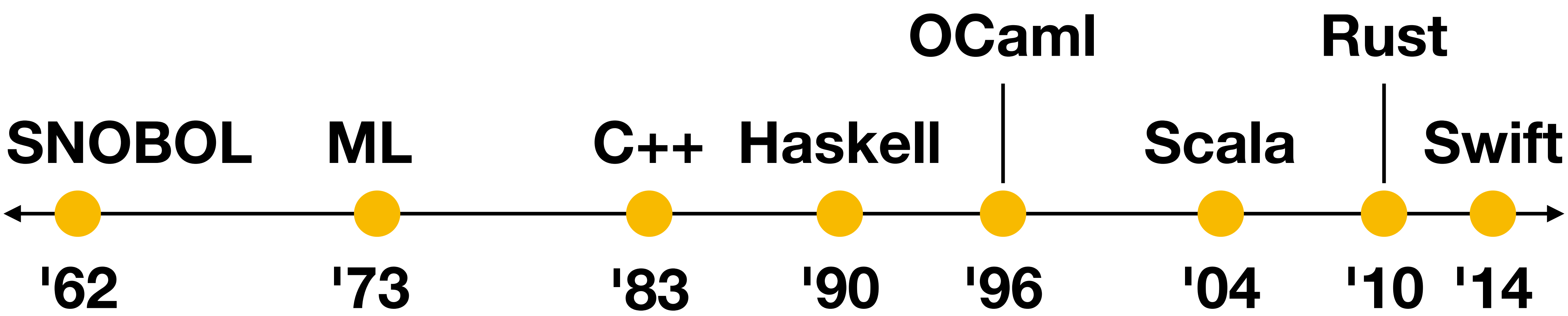
History



- Open Pattern Matching for C++ / Mach7 (2013)
  Yuriy Solodkyy, Gabriel Dos Reis, Bjarne Stroustrup

- Simple, Extensible C++ Pattern Matching Library (2015)
  John Bandela

Why doesn't C++ have feature X?

No one proposed it

Standards Proposal

- P0095R1: Pattern Matching and Language Variants (2016)
  David Sankel

- Next Revision: Pattern Matching (TBD)
  David Sankel, Michael Park

Purpose

- Familiarize pattern matching in the C++ community
- Why now? What's changed?
- Can a modern library solution be "good enough"?
    - If not, gain experience to guide the language design

Overview

- Algebraic Data Types
- What is Pattern Matching?
- Various Forms of Pattern Matching in C++
- MPark.Patterns
- Other Interesting Patterns

Algebraic Data Types

Algebraic Data Types

	Description	Example	# of Possible States
Product	one of X **AND** one of Y	`tuple<X, Y>`	$\vert X\vert \times \vert Y\vert$
Sum	one of X **OR** one of Y	`variant<X, Y>`	$\vert X\vert + \vert Y\vert$

Pattern matching is the best tool for decomposing Algebraic Data Types

What is Pattern Matching?

“In pattern matching, we attempt to **match** *values* against *patterns* and, if so desired, **bind** *variables* to successful matches.”

https://en.wikibooks.org/wiki/Haskell/Pattern_matching

“In pattern matching, we attempt to **match** *values* against *patterns* and, if so desired, **bind** *variables* to successful matches.”

```
struct Point { x: i32, y: i32 }

let  p = Point { x: 7, y: 0 };

match p {
  Point { x: 0, y    } => println!("Y axis: {}", y),
  Point { x   , y: 0 } => println!("X axis: {}", x),
  Point { x   , y    } => println!("{}, {}", x, y)
}

// prints: "X axis: 7"
```

https://en.wikibooks.org/wiki/Haskell/Pattern_matching

Pattern matching is a **declarative** approach in lieu of manually **testing** for a *value* with a *sequence of conditionals* and **extracting** the *desired components*.

```
struct Point { int x; int y; };

auto p = Point { 7, 0 };

if (p.x == 0)      printf("Y axis: %d\n", p.y);
else if (p.y == 0) printf("X axis: %d\n", p.x);
else               printf("%d, %d\n", p.x, p.y);


// prints: "X axis: 7"
```

Evaluating Expressions

```
enum Expr {
  Int(i32),
  Neg(Box<Expr>),
  Add(Box<Expr>, Box<Expr>),
  Mul(Box<Expr>, Box<Expr>),
}

fn eval(expr: Expr) -> i32 {
  return match expr {
    Expr::Int(value) => value,
    Expr::Neg(expr) => -eval(*expr),
    Expr::Add(lhs, rhs) => eval(*lhs) + eval(*rhs),
    Expr::Mul(lhs, rhs) => eval(*lhs) * eval(*rhs),
  };
}
```

values
patterns
variables

Evaluating Expressions

```
enum Expr {
  Int(i32),
  Neg(Box<Expr>),
  Add(Box<Expr>, Box<Expr>),
  Mul(Box<Expr>, Box<Expr>),
}
```

values
patterns
variables

```
fn eval(expr: Expr) -> i32 {
  return match expr {
    Expr::Int(value) => value,
    Expr::Neg(expr) => -eval(*expr),
    Expr::Add(lhs, rhs) => eval(*lhs) + eval(*rhs),
    Expr::Mul(lhs, rhs) => eval(*lhs) * eval(*rhs),
  };
}
```

sum

Evaluating Expressions

```
enum Expr {
  Int(i32),
  Neg(Box<Expr>),
  Add(Box<Expr>, Box<Expr>),
  Mul(Box<Expr>, Box<Expr>),
}

fn eval(expr: Expr) -> i32 {
  return match expr {
    Expr::Int(value) => value,
    Expr::Neg(expr) => -eval(*expr),
    Expr::Add(lhs, rhs) => eval(*lhs) + eval(*rhs),
    Expr::Mul(lhs, rhs) => eval(*lhs) * eval(*rhs),
  };
}
```

values
patterns
variables

sum

product

Evaluating Expressions

```
enum Expr {
  Int(i32),
  Neg(Box<Expr>),
  Add(Box<Expr>, Box<Expr>),
  Mul(Box<Expr>, Box<Expr>),
}

fn eval(expr: Expr) -> i32 {
  return match expr {
    Expr::Int(value) => value,
    Expr::Neg(expr) => -eval(*expr),
    Expr::Add(lhs, rhs) => eval(*lhs) + eval(*rhs),
    Expr::Mul(lhs, rhs) => eval(*lhs) * eval(*rhs),
  };
}
```

Composed Patterns!

values
patterns
variables

Evaluating Expressions

```
struct Expr { virtual ~Expr() = default; };
struct Int : Expr { int value; };
struct Neg : Expr { shared_ptr<Expr> expr; };
struct Add : Expr { shared_ptr<Expr> lhs, rhs; };
struct Mul : Expr { shared_ptr<Expr> lhs, rhs; };

int eval(const Expr &expr) {
  if (auto p = dynamic_cast<const Int *>(&expr))
    return p->value;
  if (auto p = dynamic_cast<const Neg *>(&expr))
    return -eval(*p->expr);
  if (auto p = dynamic_cast<const Add *>(&expr))
    return eval(*p->lhs) + eval(*p->rhs);
  if (auto p = dynamic_cast<const Mul *>(&expr))
    return eval(*p->lhs) * eval(*p->rhs);
  throw logic_error("unknown expression");
}
```

Evaluating Expressions

Manually **testing** for a *value* with a *sequence of conditionals* and **extracting** the *desired components*.

```
int eval(const Expr &expr) {
  if (auto p = dynamic_cast<const Int *>(&expr))
    return p->value;
  if (auto p = dynamic_cast<const Neg *>(&expr))
    return -eval(*p->expr);
  if (auto p = dynamic_cast<const Add *>(&expr))
    return eval(*p->lhs) + eval(*p->rhs);
  if (auto p = dynamic_cast<const Mul *>(&expr))
    return eval(*p->lhs) * eval(*p->rhs);
  throw logic_error("unknown expression");
}
```

LLVM

Manually **testing** for a *value* with a *sequence of conditionals* and **extracting** the *desired components*.

```
if (const auto *CE = dyn_cast<ImplicitCastExpr>(E))
  return // ...
if (const auto *RE = dyn_cast<DeclRefExpr>(E))
  return // ...
if (const auto *ME = dyn_cast<MemberExpr>(E))
  return // ...
// ...
if (const auto *CE = dyn_cast<CallExpr>(E))
  return // ...
if (const auto *CE = dyn_cast<CXXConstructExpr>(E))
  return // ...
```

Visitor

```cpp
struct Int; struct Neg; struct Add; struct Mul;

struct Expr {
  struct Vis {
    virtual void operator()(const Int &) const = 0;
    virtual void operator()(const Neg &) const = 0;
    virtual void operator()(const Add &) const = 0;
    virtual void operator()(const Mul &) const = 0;
  };

  virtual ~Expr() = default;
  virtual void accept(const Vis&) const = 0;
};

struct Int : Expr {
  void accept(const Vis& vis) const { vis(*this); }
  int value;
};

struct Neg : Expr {
  void accept(const Vis& vis) const { vis(*this); }
  shared_ptr<Expr> expr;
};

struct Add : Expr {
  void accept(const Vis& vis) const { vis(*this); }
  shared_ptr<Expr> lhs, rhs;
};

struct Mul : Expr {
  void accept(const Vis& vis) const { vis(*this); }
  shared_ptr<Expr> lhs, rhs;
};
```

```cpp
int eval(const Expr &expr) {
  struct Eval : Expr::Vis {
    void operator()(const Int &that) const {
      result = that.value;
    }
    void operator()(const Neg &that) const {
      result = -eval(*that.expr);
    },
    void operator()(const Add &that) const {
      result = eval(*that.lhs) + eval(*that.rhs);
    }
    void operator()(const Mul &that) {
      result = eval(*that.lhs) * eval(*that.rhs);
    }

    int &result;
  };

  int result;
  expr.accept(Eval{result});
  return result;
}
```

😱

Insight from Swift

"Pattern matching was probably a foregone conclusion, but I wanted to spell out that having ADTs in the language is what really forces our hand because the alternatives are so bad."

http://apple-swift.readthedocs.io/en/latest/Pattern%20Matching.html

Various Forms of Pattern Matching in C++

Various Forms of Pattern Matching in C++

- Matching Simple Types
- Matching Product Types
- Matching Sum Types

Matching Simple Types

switch

```
int x = 1;

switch (x) {
  case 1: case 2: printf("one or two\n"); break;
  case 3:         printf("three\n");      break;
  default:        printf("anything\n");
}
```

Python Style

```
string s = "c";

unordered_map<string, void (*)()>{
  { "a", [] { printf("A\n"); } },
  { "b", [] { printf("B\n"); } },
  { "c", [] { printf("C\n"); } }
}[s]()
```

Matching Product Types

```
pair<X, Y> p;
tuple<pair<X, Y>, Z> t;
```

values
patterns
variables

	Destructuring	Nested Destructuring

apply	`apply([](X x, Y y) {`
	`    // ...`
	`}, p);`
		`apply(`
		`  [](pair<X, Y> p, Z z) {`
		`    apply([z](X x, X y) {`
		`      // ...`
		`    }, p);`
		`  }, t);`

Structured Binding	`auto [x, y] = p;`	`auto [p, z] = t;`
		`auto [x, y] = p;`
		~~`auto [[x, y], z] = t;`~~

Matching Sum Types

```
struct Expr;
struct Neg { shared_ptr<Expr> expr; };
struct Add { shared_ptr<Expr> lhs, rhs; };
struct Mul { shared_ptr<Expr> lhs, rhs; };
struct Expr : variant<int, Neg, Add, Mul> {
  using variant::variant;
};
```

values
patterns
variables

```
int eval(const Expr &expr) {
  return visit(overload(
    [](int value) { return value; },
    [](const Neg &n) { return -eval(*n.expr); },
    [](const Add &a) { return eval(*a.lhs) + eval(*a.rhs); },
    [](const Mul &m) { return eval(*m.lhs) * eval(*m.rhs); }),
    expr);
}
```

MPark.Patterns

Main Goals

- Declarative
- Structured
- Cohesive
- Composable

Basic Structure

values
patterns
variables

```
#include <mpark/patterns.hpp>

using namespace mpark::patterns;  // omitted from here on
match(<expr>...)(
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  // ...
);
```

Back to the `Point`

```
struct Point { int x; int y; };

auto p = Point { 7, 0 };

match(p)(
  pattern(ds(0  , arg)) = [](int y) {
    printf("Y axis: %d\n", y);
  },
  pattern(ds(arg, 0  )) = [](int x) {
    printf("X axis: %d\n", x);
  },
  pattern(ds(arg, arg)) = [](int x, int y) {
    printf("%d, %d\n", x, y);
  }
);

// prints: "X axis: 7"
```

values
patterns
variables

Re: Evaluating Expressions

values
patterns
variables

```
struct Expr;

struct Neg { shared_ptr<Expr> expr; };
struct Add { shared_ptr<Expr> lhs, rhs; };
struct Mul { shared_ptr<Expr> lhs, rhs; };

struct Expr : variant<int, Neg, Add, Mul> {
  using variant::variant;
};

namespace std {

  template <>
  struct variant_size<Expr>  // Opt into `VariantLike`
    : integral_constant<size_t, 4> {};

}  // namespace std
```

Re: Evaluating Expressions

```
int eval(const Expr &expr) {
  return match(expr)(
    pattern(as<int>(arg)) = [](int value) {
      return value;
    },
    pattern(as<Neg>(ds(arg))) = [](auto &expr) {
      return -eval(*expr);
    },
    pattern(as<Add>(ds(arg, arg))) = [](auto &lhs, auto &rhs) {
      return eval(*lhs) + eval(*rhs);
    },
    pattern(as<Mul>(ds(arg, arg))) = [](auto &lhs, auto &rhs) {
      return eval(*lhs) * eval(*rhs);
    }
  );
}
```

values
patterns
variables

Optional Flag

values
patterns
variables

```
optional<string> flag = "-v";

match(flag)(
  pattern(some(arg(anyof("-v", "--verbose")))) = [](auto &flag) {
    // `flag` == "-v" or "--verbose"
  },
  pattern(some(arg)) = [](auto &flag) {
    WHEN(starts_with(flag, "-W")) {  // pattern guard!
      // ...
    };
  },
  pattern(some(_)) = [] { printf("unknown flag!"); }
  pattern(none) = [] {}
);
```

Patterns So Far

Pattern	Matches	Example
Expression	Any	`0`
Arg / Wildcard	Any	`arg / _`
Destructure	Array, Aggregate, TupleLike	`ds(0, _)`
As	Polymorphic, VariantLike, AnyLike	`as<Add>(arg)`
Optional	PointerLike	`some(_), none`
Alternation	One of N Patterns	`anyof("-f", "--force")`

Simplifying Expressions

Let's simplify the expression tree we've been evaluating.

Simplification Rules:

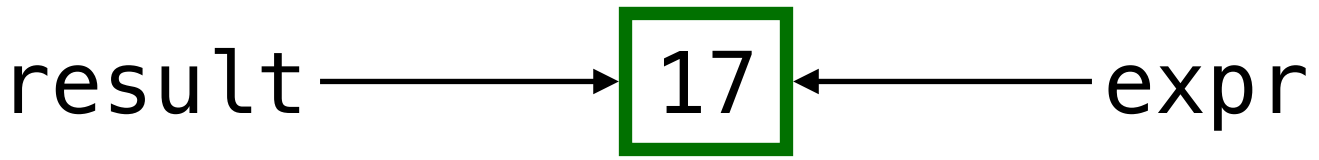
- `-(-v) == v`
- `v + 0 == v`
- `v × 1 == v`
- `v × 0 == 0`

Simplifying Expressions

```
struct Expr;

struct Neg { shared_ptr<Expr> expr; };
struct Add { shared_ptr<Expr> lhs, rhs; };
struct Mul { shared_ptr<Expr> lhs, rhs; };

struct Expr : variant<int, Neg, Add, Mul> {
  using variant::variant;
};

namespace std {

  template <>
  struct variant_size<Expr>  // Opt into `VariantLike`
    : integral_constant<size_t, 4> {};

}  // namespace std
```

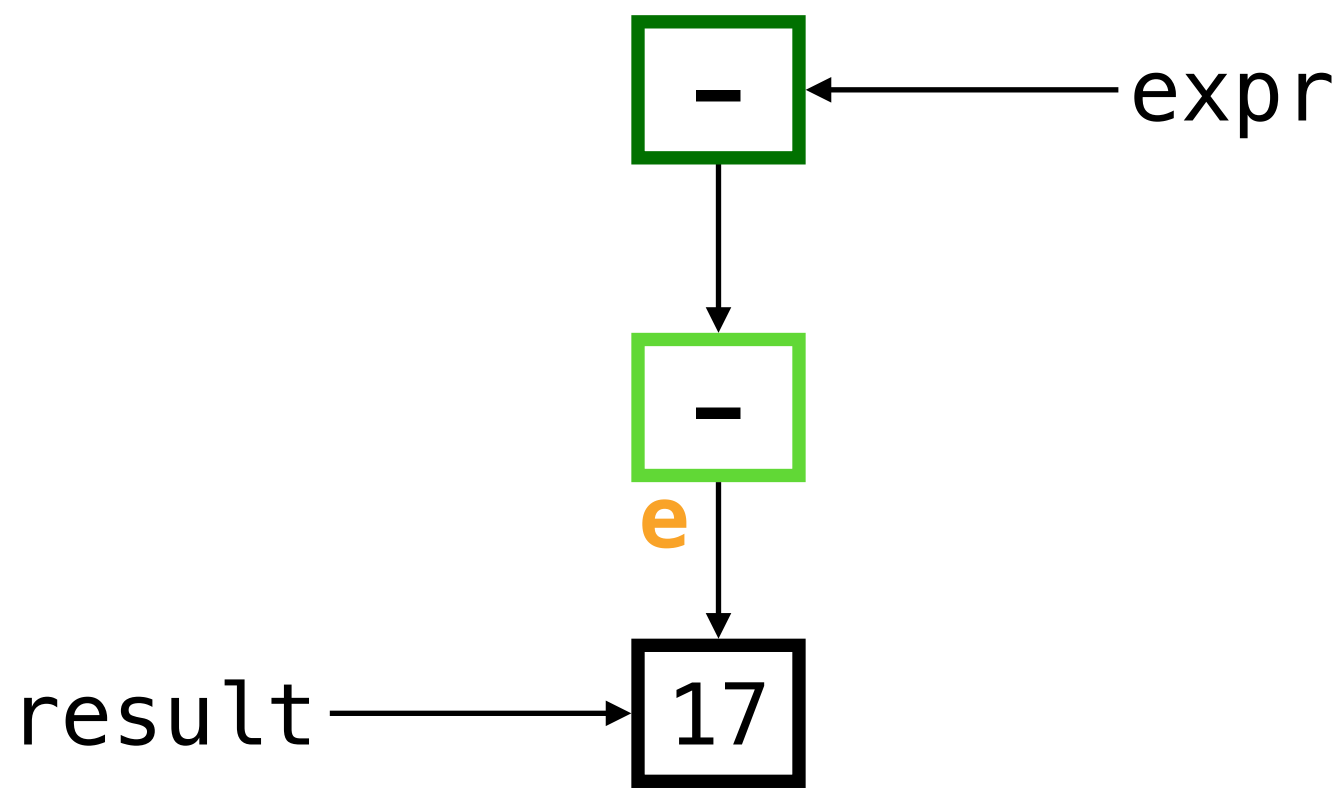
Simplifying `int`

```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    pattern(as<int>(_)) = [&] { return expr; },
    // ...
  );
}
```



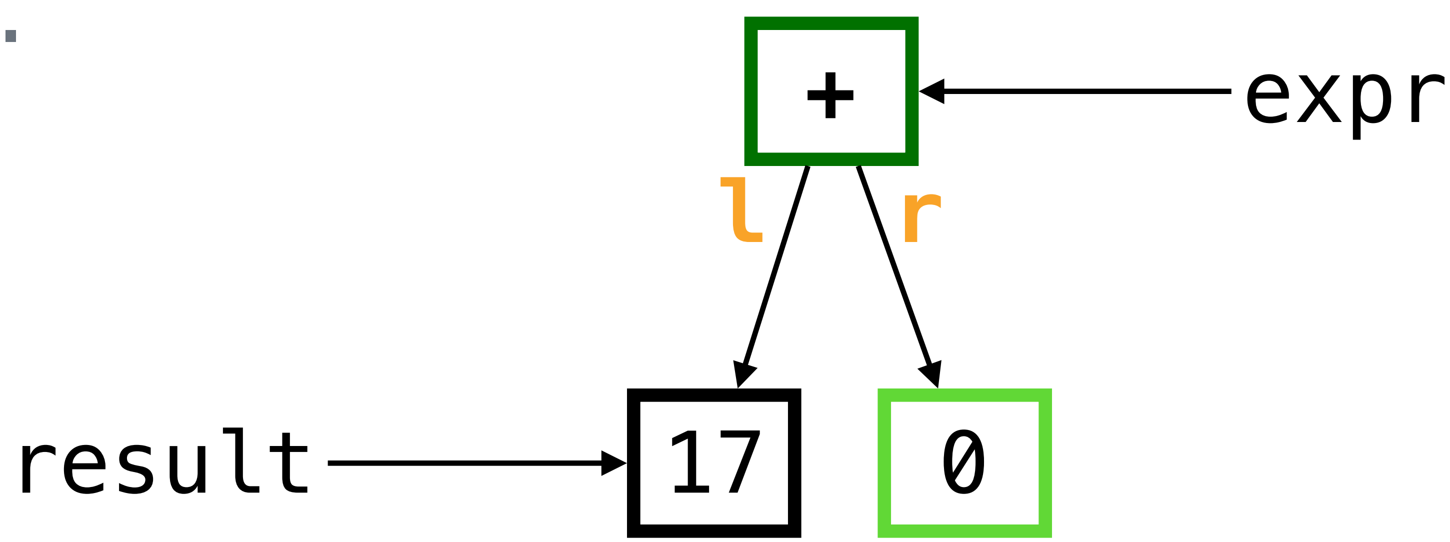
Simplifying –(–v)

```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Neg>(ds(some(as<Neg>(ds(arg)))))) = [](auto &e) {
      return simplify(e);
    },
    // ...
  );
}
```



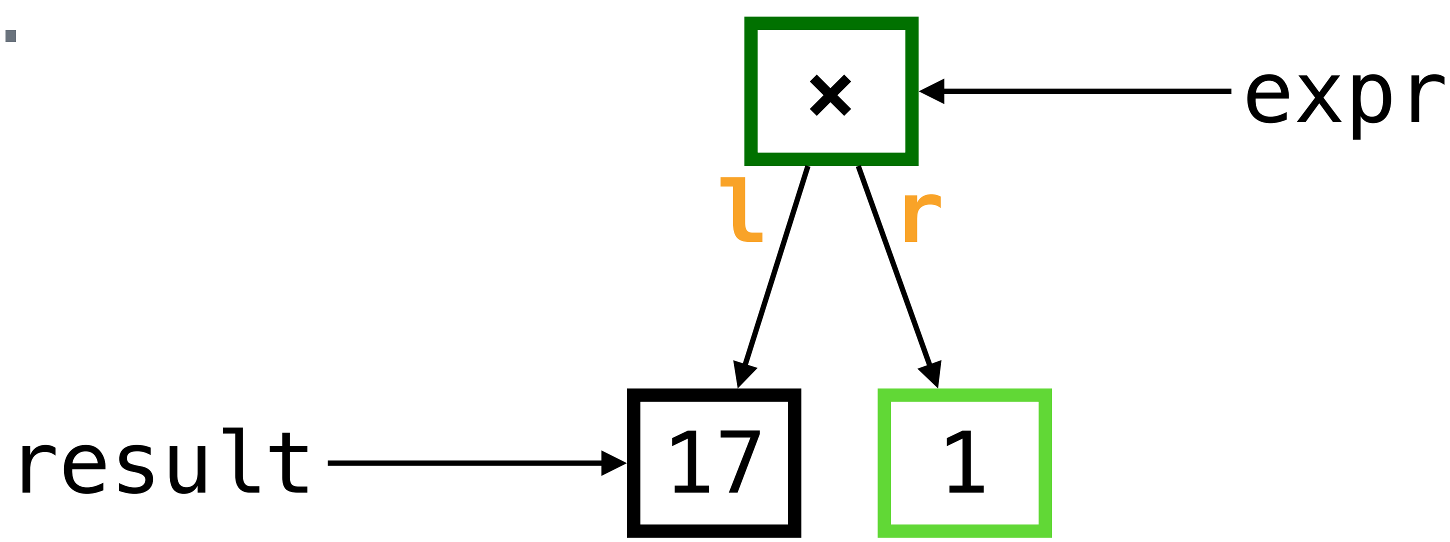
Simplifying `v + 0`

```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Add>(ds(some(as<int>(0)), arg))) = [](auto &r) {
      return simplify(r);
    },
    pattern(as<Add>(ds(arg, some(as<int>(0))))) = [](auto &l) {
      return simplify(l);
    },
    // ...
  );
}
```



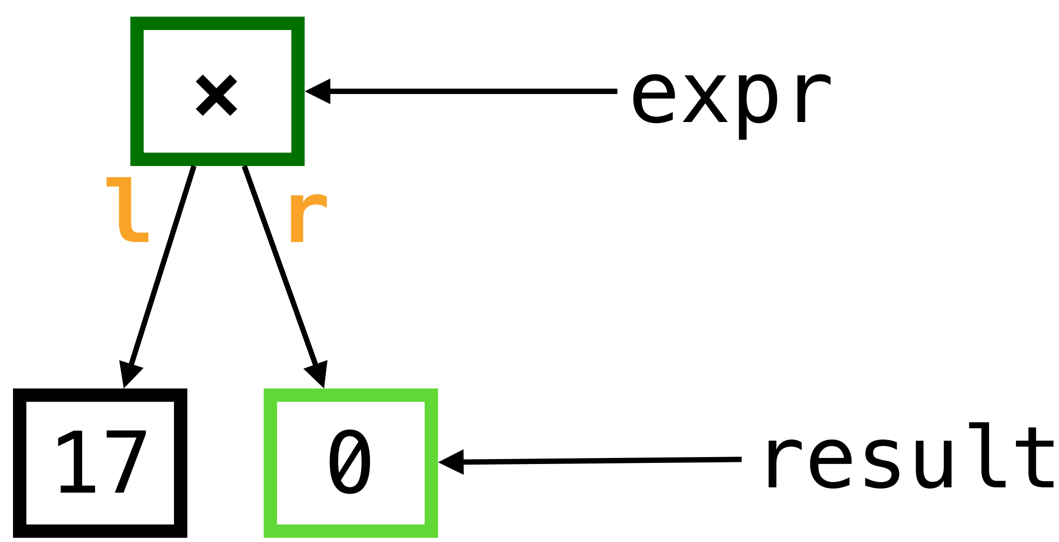
Simplifying v × 1

```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Mul>(ds(some(as<int>(1)), arg))) = [](auto &r) {
      return simplify(r);
    },
    pattern(as<Mul>(ds(arg, some(as<int>(1))))) = [](auto &l) {
      return simplify(l);
    },
    // ...
  );
}
```



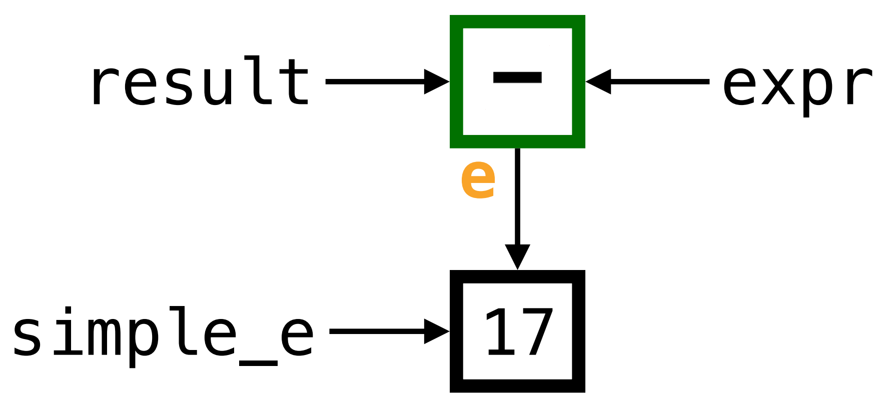
Simplifying `v × 0`

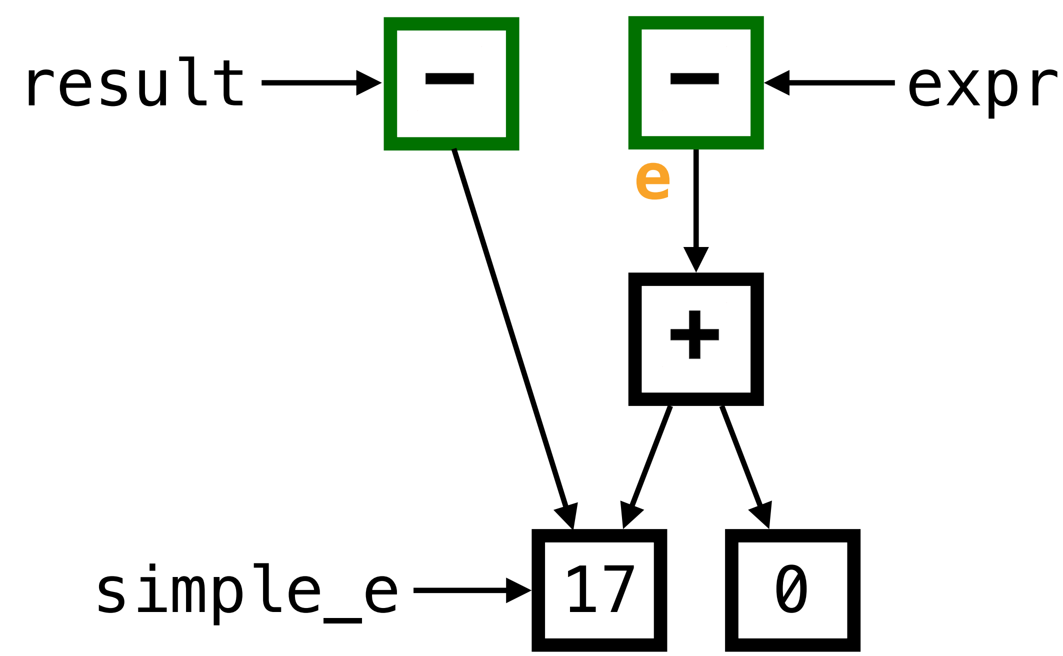
```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Mul>(ds(arg(some(as<int>(0))), _))) = [](auto &l) {
      return l;
    },
    pattern(as<Mul>(ds(_, arg(some(as<int>(0)))))) = [](auto &r) {
      return r;
    },
    // ...
  );
}
```



Simplifying –

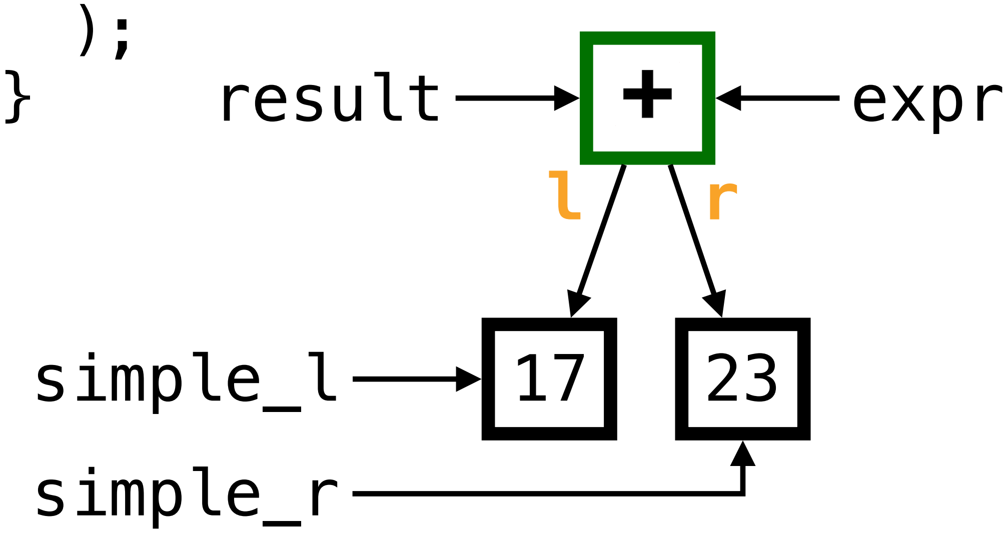
```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Neg>(ds(arg))) = [&](auto &e) {
      auto simple_e = simplify(e);
      return simple_e == e
                 ? expr
                 : simplify(make_shared<Expr>(Neg{simple_e}));
    },
    // ...
  );
}
```

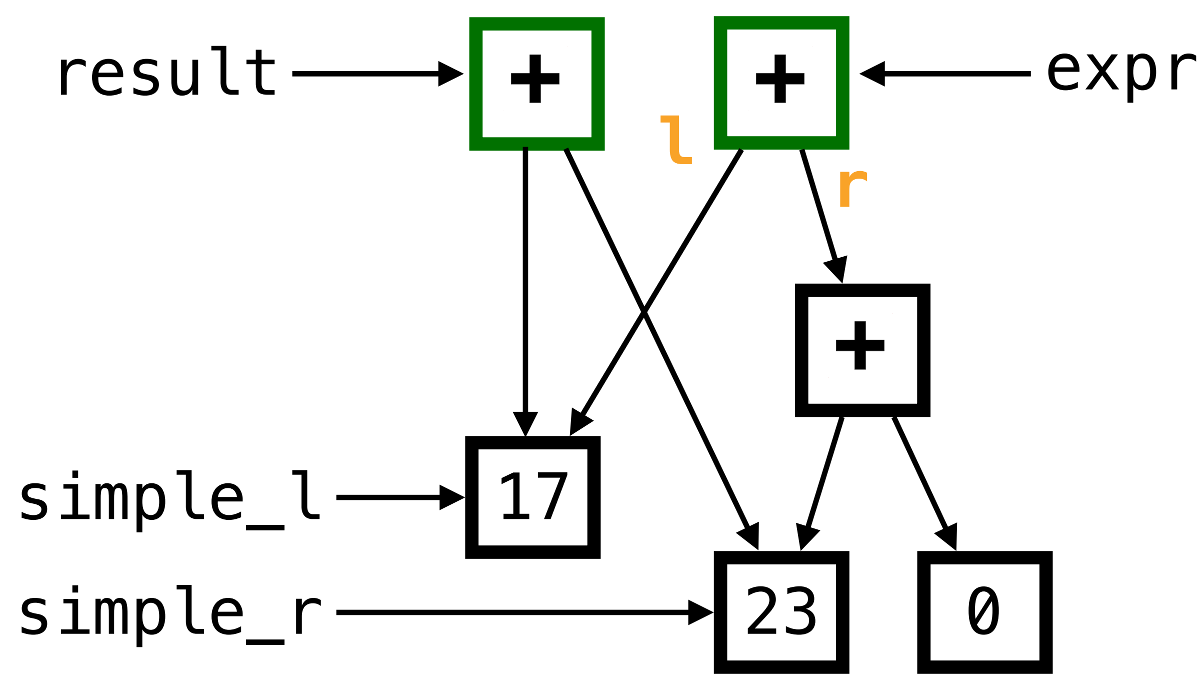




Simplifying +

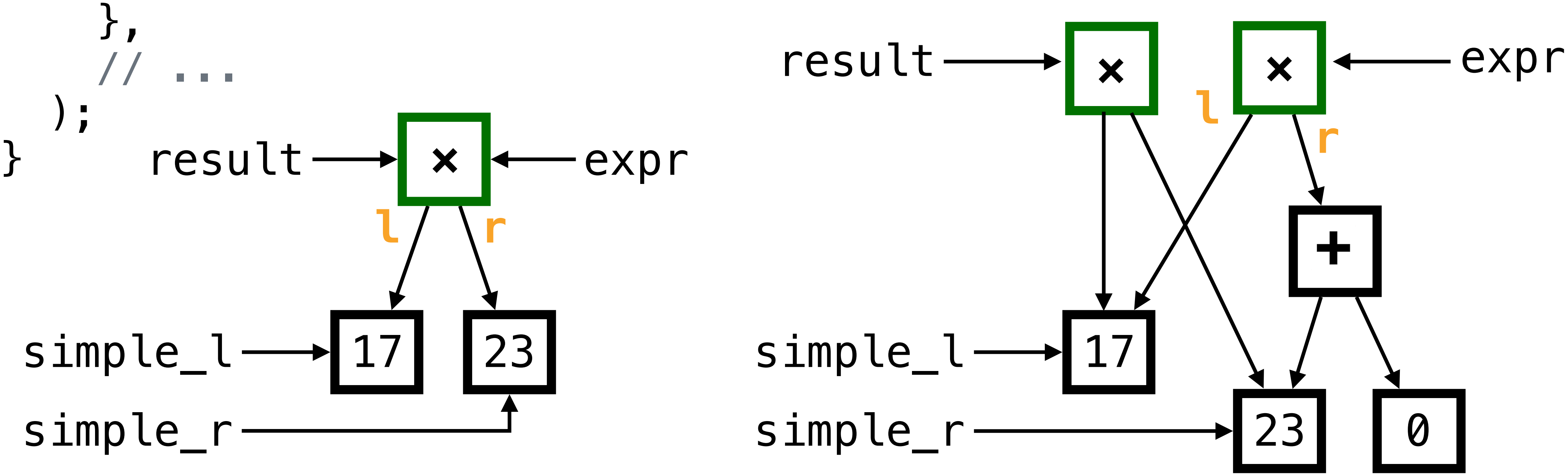
```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Add>(ds(arg, arg))) = [&](auto &l, auto &r) {
      auto simple_l = simplify(l), simple_r = simplify(r);
      return simple_l == l && simple_r == r
                 ? expr
                 : simplify(make_shared<Expr>(Add{simple_l,
                                                   simple_r}));
    },
    // ...
  );
}
```





Simplifying ×

```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    // ...
    pattern(as<Mul>(ds(arg, arg))) = [&](auto &l, auto &r) {
      auto simple_l = simplify(l), simple_r = simplify(r);
      return simple_l == l && simple_r == r
                 ? expr
                 : simplify(make_shared<Expr>(Mul{simple_l,
                                                   simple_r}));
    },
    // ...
  );
}
```



Putting it all together

```
shared_ptr<Expr> simplify(const shared_ptr<Expr> &expr) {
  return match(*expr)(
    pattern(as<int>(_)) = [&] { return expr; },  // v
    pattern(
      anyof(as<Neg>(ds(some(as<Neg>(ds(arg))))), // -(-v)
            as<Add>(ds(some(as<int>(0)), arg)),  // v + 0
            as<Add>(ds(arg, some(as<int>(0)))),
            as<Mul>(ds(some(as<int>(1)), arg)),  // v * 1
            as<Mul>(ds(arg, some(as<int>(1))))) = [](auto &e) {
      return simplify(e);
    },
    pattern(
      anyof(as<Mul>(ds(arg(some(as<int>(0))), _)),  // v * 0
            as<Mul>(ds(_, arg(some(as<int>(0)))))) = [](auto &zero) {
      return zero;
    },
    pattern(as<Neg>(ds(arg))) = [&](auto &e) { /* ... */ },
    pattern(as<Add>(ds(arg, arg))) = [&](auto &l, auto &r) { /* ... */ },
    pattern(as<Mul>(ds(arg, arg))) = [&](auto &l, auto &r) { /* ... */ }
  );
}
```

The real power of pattern matching is that the patterns are built the same way as the values

A Few More Things...

Identifiers

- Typically introduced inside the pattern, but...
- Introduced as parameters of a lambda instead
- Patterns do not have any identifiers

Pattern Guard

```
int fib(int n) {
  return match(n)(
           pattern(arg) = [](int x) {
             WHEN(x <= 0) { return 0; };
           },
           pattern(1) = [] { return 1; },
           pattern(arg) = [](int x) {
             return fib_v1(x - 1) + fib_v1(x - 2);
           });
}
```

- Lives inside the handler... why?
- Reusing the identifier introduced in the lambda

Identifier Pattern

```
struct Point { int x; int y; };
auto p = Point { 7, 0 };

IDENTIFIERS(x, y);
match(p)(
  pattern(ds(0  , y  )) = [](int y) {
    printf("Y axis: %d\n", y);
  },
  pattern(ds(x  , 0  )) = [](int x) {
    printf("X axis: %d\n", x);
  },
  pattern(ds(x  , y  )) = [](int x, int y) {
    printf("%d, %d\n", x, y);
  }
);

// prints: "X axis: 7"
```

Identifier Pattern

Repeated identifiers mean the values have to be equal!

```
tuple<int, int, int> t = { 101, 202, 101 };

IDENTIFIERS(x, y);
match(t)(
  pattern(ds(x, x, x)) = [] { printf("all the same!"); },
  pattern(ds(x, y, x)) = [] { printf("bordered!"); },
  pattern(_) = [] { printf("No recognized pattern"); });

// prints: "bordered!"
```

Back to the Pattern Guard

```
int fib(int n) {
  IDENTIFIERS(x);
  return match(n)(
      pattern(x).when(x <= 0) = [](int) { return 0; },
      pattern(1) = [] { return 1; },
      pattern(x) = [](int x) {
        return fib_v1(x - 1) + fib_v1(x - 2);
     });
}
```

Variadic Pattern

Syntax: **`variadic(<pattern>)`**

- Exactly once anywhere within a Destructure Pattern
- The inner pattern is repeatedly expanded as necessary

```
tuple<int, int, int> t = { 101, 202, 101 };

match(t)(
  pattern(ds(arg, arg, arg)) = [](auto, auto, auto) {});

match(t)(
  pattern(ds(variadic(arg))) = [](auto, auto, auto) {});
```

Inside of a `template`

```
template <typename Tuple>
void print(Tuple &&tuple) {
  match(forward<Tuple>(tuple))(
    pattern(ds(variadic(arg))) = [](auto &&... xs) {
      int dummy[] = { (cout << xs << ' ', 0)... };
      (void)dummy;
    }
  );
}

print(tuple(101, "hello", 1.1));

// prints: "101 hello 1.1 "
```

This is C++17 `apply`!

```
template <typename F, typename Tuple>
decltype(auto) apply(F &&f, Tuple &&t) {
  return match(forward<T>(t))(
      pattern(ds(variadic(arg))) = forward<F>(f));
}
```

almost `tuple_cat`

```
tuple<int, int, int> t = { 101, 202, 101 };

match(t)(
  pattern(ds(variadic(arg))) = [](auto, auto, auto) {});
```

almost `tuple_cat`

```
template <typename... Tuples>
auto almost_tuple_cat(Tuples &&... tuples) {
  return match(forward<Tuples>(tuples)...)(
    pattern(variadic(ds(variadic(arg)))) = [](auto &&... xs) {
      return make_tuple(forward<decltype(xs)>(xs)...);
    });
}
```

Performance

MPark.Patterns

```
void fizzbuzz() {
  using namespace mpark::patterns;
  for (int i = 1; i <= 100; ++i) {
    match(i % 3, i % 5)(
        pattern(0, 0) = [] { std::printf("fizzbuzz\n"); },
        pattern(0, _) = [] { std::printf("fizz\n"); },
        pattern(_, 0) = [] { std::printf("buzz\n"); },
        pattern(_, _) = [i] { std::printf("%d\n", i); });
  }
}
```

switch

```
void fizzbuzz() {
  for (int i = 1; i <= 100; ++i) {
    switch (i % 3) {
      case 0:
        switch (i % 5) {
          case 0: std::printf("fizzbuzz\n"); break;
          default: std::printf("fizz\n"); break;
        }
        break;
      default:
        switch (i % 5) {
          case 0: std::printf("buzz\n"); break;
          default: std::printf("%d\n", i); break;
        }
        break;
    }
  }
}
```

Exactly the same generated code!

```
fizzbuzz(): # @fizzbuzz()
  push rbx
  mov ebx, 1
.LBB0_1: # =>This Inner Loop Header: Depth=1
  movsxd rcx, ebx
  imul rax, rcx, 1431655766
  mov rdx, rax
  shr rdx, 63
  shr rax, 32
  add eax, edx
  lea edx, [rax + 2*rax]
  imul rax, rcx, 1717986919
  mov rsi, rax
  shr rsi, 63
  sar rax, 33
  add eax, esi
  lea esi, [rax + 4*rax]
  mov eax, ecx
  sub eax, esi
  cmp ecx, edx
  je .LBB0_4
  test eax, eax
  je .LBB0_6
  mov edi, .L.str.3
  xor eax, eax
  mov esi, ebx
  call printf
  jmp .LBB0_9
.LBB0_4: # in Loop: Header=BB0_1 Depth=1
  test eax, eax
  je .LBB0_7
  mov edi, .Lstr.4
  jmp .LBB0_8
.LBB0_6: # in Loop: Header=BB0_1 Depth=1
  mov edi, .Lstr
  jmp .LBB0_8
.LBB0_7: # in Loop: Header=BB0_1 Depth=1
  mov edi, .Lstr.5
.LBB0_8: # in Loop: Header=BB0_1 Depth=1
  call puts
.LBB0_9: # in Loop: Header=BB0_1 Depth=1
  inc ebx
  cmp ebx, 101
  jne .LBB0_1
  pop rbx
  ret
main: # @main
  push rbx
  mov ebx, 1
.LBB1_1: # =>This Inner Loop Header: Depth=1
  movsxd rcx, ebx
  imul rax, rcx, 1431655766
  mov rdx, rax
  shr rdx, 63
  shr rax, 32
  add eax, edx
  lea edx, [rax + 2*rax]
  imul rax, rcx, 1717986919
  mov rsi, rax
  shr rsi, 63
  sar rax, 33
  add eax, esi
  lea esi, [rax + 4*rax]
  mov eax, ecx
  sub eax, esi
  cmp ecx, edx
  je .LBB1_4
  test eax, eax
  je .LBB1_6
  mov edi, .L.str.3
  xor eax, eax
  mov esi, ebx
  call printf
  jmp .LBB1_9
.LBB1_4: # in Loop: Header=BB1_1 Depth=1
  test eax, eax
  je .LBB1_7
  mov edi, .Lstr.4
  jmp .LBB1_8
.LBB1_6: # in Loop: Header=BB1_1 Depth=1
  mov edi, .Lstr
  jmp .LBB1_8
.LBB1_7: # in Loop: Header=BB1_1 Depth=1
  mov edi, .Lstr.5
.LBB1_8: # in Loop: Header=BB1_1 Depth=1
  call puts
.LBB1_9: # in Loop: Header=BB1_1 Depth=1
  inc ebx
  cmp ebx, 101
  jne .LBB1_1
  xor eax, eax
  pop rbx
  ret
.L.str.3:
  .asciz "%d\n"

.Lstr:
  .asciz "buzz"

.Lstr.4:
  .asciz "fizz"

.Lstr.5:
  .asciz "fizzbuzz"
```

Future Work

Future Work

- Determine an API for Ranges
- Experiment further with identifiers
- Exhaustiveness checking

MPark.Patterns

Pattern Matching in C++

https://github.com/mpark/patterns

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MESOSPHERE

Implementation Peek

Structure

```
using namespace mpark::patterns;
IDENTIFIERS(<identifier>...);  // optional
match(<expr>...)(
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  // ...
);
```

Structure

```
using namespace mpark::patterns;
IDENTIFIERS(<identifier>...);  // optional
match(<expr>...)(
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  // ...
);
```

```
template <typename... Patterns>
struct Pattern {
   template <typename F>
   Case<Pattern, F> operator=(F &&f) && noexcept;

   Ds<Patterns &&...> patterns;
};
```

Structure

```
using namespace mpark::patterns;
IDENTIFIERS(<identifier>...);  // optional
match(<expr>...)(
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  // ...
);

template <typename Pattern, typename F>
struct Case {
  Pattern pattern;
  F f;
};
```

Structure

```
using namespace mpark::patterns;
IDENTIFIERS(<identifier>...);  // optional
match(<expr>...)(
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  pattern(<pattern>...) = [](<binding>...) { /* ... */ },
  // ...
);
```

```
template <typename... Values>
struct Match {
  template <typename Pattern, typename F, typename... Cases>
  decltype(auto) operator()(Case<Pattern, F> &&case_,
                            Cases&&... cases) && {
    // ...
  }

  tuple<Values &&...> values;
}
```

Match::operator()

```
template <typename Pattern, typename F, typename... Cases>
decltype(auto) operator()(Case<Pattern, F> &&case_,
                          Cases&&... cases) && {
  auto result = try_match(move(case_).pattern.patterns,
                          move(values),
                          move(case_).f);
  if (result) {
    return move(result).get();
  }

  if constexpr (sizeof...(Cases) == 0) {
    throw match_error{};
  } else {
    return move(*this)(forward<Cases>(cases)...);
  }
}
```

Match::operator()

```
template <typename Pattern, typename F, typename... Cases>
decltype(auto) operator()(Case<Pattern, F> &&case_,
                          Cases&&... cases) && {
  auto result = try_match(move(case_).pattern.patterns,
                          move(values),
                          move(case_).f);

  if (result) {
    return move(result).get();
  }

  if constexpr (sizeof...(Cases) == 0) {
    throw match_error{};
  } else {
    return move(*this)(forward<Cases>(cases)...);
  }
}
```

match_result<T>

```
template <typename T>
struct match_result : optional<forwarder<T>> {
  using type = T;

  using super = optional<forwarder<T>>;
  using super::super;

  match_result(no_match_t) noexcept {}
  match_result(nullopt_t) = delete;

  decltype(auto) get() && {
    return (*static_cast<super &&>(*this)).forward();
  }
};
```

match_result-aware invoke

```
// `invoke`-like utility for `try_match` functions.
template <typename F, typename... Args>
auto match_invoke(F &&f, Args &&... args) {
  using R = invoke_result_t<F, Args...>;
  if constexpr (is_void_v<R>) {
    invoke(forward<F>(f), forward<Args>(args)...);
    return match_result<void>(void_{});
  } else if constexpr (is_match_result_v<R>) {
    return invoke(forward<F>(f), forward<Args>(args)...);
  } else {
    return match_result<R>(
        invoke(forward<F>(f), forward<Args>(args)...));
  }
}
```

Expression Pattern

```
template <typename ExprPattern, typename Value, typename F>
auto try_match(const ExprPattern &expr_pattern,
               Value &&value,
               F &&f) {
  return expr_pattern == forward<Value>(value)
             ? match_invoke(forward<F>(f))
             : no_match;
}
```

Arg Pattern

```
template <typename Pattern, typename Value, typename F>
auto try_match(const Arg<Pattern> &arg,
               Value &&value,
               F &&f) {
  if constexpr (is_void_v<Pattern>) {
    return match_invoke(forward<F>(f),
                        forward<Value>(value));
  } else {
    return try_match(arg.pattern,
                     forward<Value>(value),
                     forward<F>(f));
  }
}
```