
accu
2021
VIRTUAL EVENT
Bloomberg
Engineering
undo
mosaic
CONSULTANTS TO FINANCIAL SERVICES
The Point Challenge:
Returning Different Types
for the Same Operation
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# Strong Types

```
Distance distance(Duration t, Speed s) {
    return t * s; // distance = time * speed
}

// usage:
auto d = distance(1.5h, 10_kmh);  // 1.5h = 1.5 hours (std::chrono duration)
                                  // 10_kmh = 10 km/h (with our own literal type)

// following would fail to compile:
auto d1 = distance(1h, 1h);
auto d2 = distance(10_km, 10_kmh);
```

# Strong Types - not every operation is allowed!

```
// future / historical point in time - ok
Time operator+(Time p, Duration t);
Time operator+(Duration t, Time t);

// Duration between points in time - ok
Duration operator-(Time p1, Time p2);

// adding or subtracting durations - ok
Duration operator+(Duration d1, Duration d2);
Duration operator-(Duration d1, Duration d2);

// But the following should NOT be allowed:
operator+(Time p1, Time p2); // 12:00pm + 9:00am = ??
```

# Point Arithmetics

```
Point p1 {3, 7};   // assume proper ctor
Point p2 {10, 10};
```

```
Point p3 = p1 + p2;
```

**Should we allow adding two points?**

# Point Arithmetics

```
Point p1 {3, 7};  // assume proper ctor
Point p2 {10, 10};
```

```
Point p3 = p1 + p2;
```

**Should we allow adding two points?**

What does {13, 17} represent?

Maybe there is a point in adding Point and *PointDiff*...
But two points?

# Point Arithmetics

```
Point p1 {3, 7};   // assume proper ctor
Point p2 {10, 10};
```

```
Point p3 = p1 + p2;
```

On the other hand maybe there is a need…

# Point Arithmetics

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Point p1 {3, 7};  // assume proper ctor
Point p2 {10, 10};
```

```
Point p3 = p1 + p2;
```

On the other hand maybe there is a need…

Averaging:

```
Point middle = (p1 + p2) / 2;
```

# Adding two Points

```
auto twoPoints = p1 + p2;
```

Then, averaging:

```
Point middle = twoPoints / 2;
```

# Adding two Points

```
auto twoPoints = p1 + p2;
```
// what should be the type of *twoPoints*?

Then, averaging:

```
Point middle = twoPoints / 2;
```

# Multiplying by N

```
auto twoPoints = p1 * 2;
```

Should we allow that ?

# Multiplying by N

```
// p3 should be closer to p2 (in ratio ⅓ <=> ⅔):
Point p3 = (p1 + p2 * 2) / 3;

// however, (p2 * 2) shouldn’t be a point!
```

# Dividing by N

```
// p3 should be closer to p2 (in ratio ⅓ <=> ⅔):
Point p3 = p1 / 3 + 2 * p2 / 3;

// however, (p1 / 3) and (2 * p2 / 3) shouldn’t be points!
```

# The Challenge

**Allow**:

- **Adding Points (2 points, 3 points, N points)**
- **Multiplying and Dividing by any number**
- **Result cannot be used as *a Point* unless getting it back to a Single Unit Point**

**Rules**:

- **We would rely only on compile time information**
- **Implementation shouldn’t be specific to class Point**

# Explaining the rules (pseudo code)

```
auto twoPoints = p1 + p2; // twoPoints is NOT a Point

// middle is a Point, but only since 2 is known at compile time
Point middle = twoPoints / 2;

auto thirdOfP1 = p1 / 3; // is NOT a Point
auto twoThirdsOfP2 = p2 * 2 / 3; // is NOT a Point

Point closerToP2 = thirdOfP1 + twoThirdsOfP2; // is a Point!
```

# Step 1

```
// that’s not a good approach… just let’s review it…
TwoPoints operator+(Point p1, Point p2) {
    return TwoPoints{p1, p2};
}

// for class TwoPoints
Point TwoPoints::operator/(int num) {
    // how can we tell if num == 2 and the operation is allowed?
}
```

# Step 1 - before C++17 - Specialization

```
// “base template” for Divider - we do not allow dividing by any number rather than 2
template<class T, int num> struct Divider;

// specialized version for Divider
template<class T> struct Divider<T, 2> {
    static T divide() { return T{}; }
};
```

```
Point TwoPoints::operator/(int num) {
    return Divider<Point, num>::divide();
}
```

Oops...

# Step 1 - before C++17 - Specialization

```
// “base template” for Divider - we do not allow dividing by any number rather than 2
template<class T, int num> struct Divider;

// specialized version for Divider
template<class T> struct Divider<T, 2> {
    static T divide() { return T{}; }
};
```

```
template<int num> Point TwoPoints::operator/(int) {
    return Divider<Point, num>::divide();
}
```

<= Now OK, but ugly

# Step 1 - before C++17 - Specialization

```
// “base template” for Divider - we do not allow dividing by any number rather than 2
template<class T, int num> struct Divider;

// specialized version for Divider
template<class T> struct Divider<T, 2> {
    static T divide() { return T{}; }
};
```

```
template<int num>
Point TwoPoints::operator/(Number<num>) {
    return Divider<Point, num>::divide();
}
```

<= Now OK

# Step 1 - before C++17 - class Number

```
template<int num> class Number {};
```

# Step 1 - before C++17 - main

```
int main() {
    Point p = TwoPoints{} / Number<2>();
}
```

http://coliru.stacked-crooked.com/a/7fda5ead44c0eef5

# Step 2 - replace Number<int> with...

```
std::ratio<N, D>
```

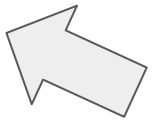
```
    Point p1 = TwoPoints{} / std::ratio<2>();

    auto twoThirdsOfaPoint = Point{} * std::ratio<2, 3>();
```

# Step 3 - use a generic “*Aggregator*” (instead of “TwoPoints”...)

```
template<class T, long Numerator = 1, long Denominator = 1>
class Aggregator {
    T t;
public:
    …

};
```



operator+
operator/
operator*

return either T or Aggregator<T, …>

# Step 3 - Point

```
class Point {
    double x, y;
public:
    Point(double x1, double y1): x(x1), y(y1) {}

    friend Aggregator<Point, 2> operator+(Point p1, Point p2) {
        return Aggregator<Point, 2>{Point{p1.x + p2.x, p1.y + p2.y}};
    }

    …
```

# Step 4 - “*Aggregator*” using C++17 *if constexpr*

```
template<class T1, long Numerator1, long Denominator1,
        long MultNum, long MultDenom>
auto constexpr operator*(Aggregator<T1, Numerator1, Denominator1> a,
                                 std::ratio<MultNum, MultDenom> n) {

    if constexpr(Numerator1*MultNum != Denominator1*MultDenom) {
        return Aggregator<T1, Numerator1*MultNum, Denominator1*MultDenom>
                {a.getT()};

    } else {
        return a.getT().unsafe_multiply(n);
    }
}
```

# Step 4 - “*Aggregator*” using C++17 *if constexpr*

```
template<class T1, long Numerator1, long Denominator1,
        long MultNum, long MultDenom>
auto constexpr operator*(Aggregator<T1, Numerator1, Denominator1> a,
                         std::ratio<MultNum, MultDenom> n) {
    if constexpr(Numerator1*MultNum != Denominator1*MultDenom) {
        return Aggregator<T1, Numerator1*MultNum, Denominator1*MultDenom>
                {a.getT()};
    } else {
        return a.getT().unsafe_multiply(n);
    }
}
```

# Step 4 - “*Aggregator*” using C++17 *if constexpr*

```
template<class T1, long Numerator1, long Denominator1,
        long MultNum, long MultDenom>
auto constexpr operator*(Aggregator<T1, Numerator1, Denominator1> a,
                                 std::ratio<MultNum, MultDenom> n) {

    if constexpr(Numerator1*MultNum != Denominator1*MultDenom) {
        return Aggregator<T1, Numerator1*MultNum, Denominator1*MultDenom>
                {a.getT()};
    } else {
        return a.getT().unsafe_multiply(n);
    }
}
```

# and it works...

```
Point p1 { 5, 10 }, p2 { 25, 30 };

std::cout << "p1 + p2: " << p1 + p2 << std::endl;

    // prints: p1 + p2: [ Aggregate (2/1) ] : {30,40}

std::cout << "(p1 + p2)/2: " << (p1 + p2) / std::ratio<2>() << std::endl;

    // prints: (p1 + p2)/2: {15,20}
```

# …we can even calculate average

```
auto s = sum(p1, p2, p3 * std::ratio<2>()); // variadic template method sum

std::cout << "average = " << s.average() << std::endl;
```

http://coliru.stacked-crooked.com/a/fd1e09191504e5e5

Same code, with friend functions implemented outside the template class:
https://godbolt.org/z/GsgL2F

(to comply with http://www.open-std.org/jtc1/sc22/wg21/docs/cwg_defects.html#2174)

# See also (1)

Adi Shavit’s blog:
http://videocortex.io/2018/Affine-Space-Types

This talk ignores overflow and signed/unsigned issues.
To take that into account see:
CppCon 2019: Marshall Clow “std::midpoint? How Hard Could it Be?”

# See also (2)

boost::units
CppCon 2015: Robert Ramey “Boost Units”

https://github.com/nholthaus/units
https://github.com/pierreblavy2/unit_lite
https://github.com/bernedom/SI
https://github.com/mpusz/units

Jonathan Boccara’s NamedType:
https://github.com/joboccara/NamedType

# Thank you!

```
void conclude(auto greetings) {
    while(still_time() && have_questions()) {
        ask();
    }
    greetings();
}

conclude([]{ std::cout << "Thank you!"; });
```