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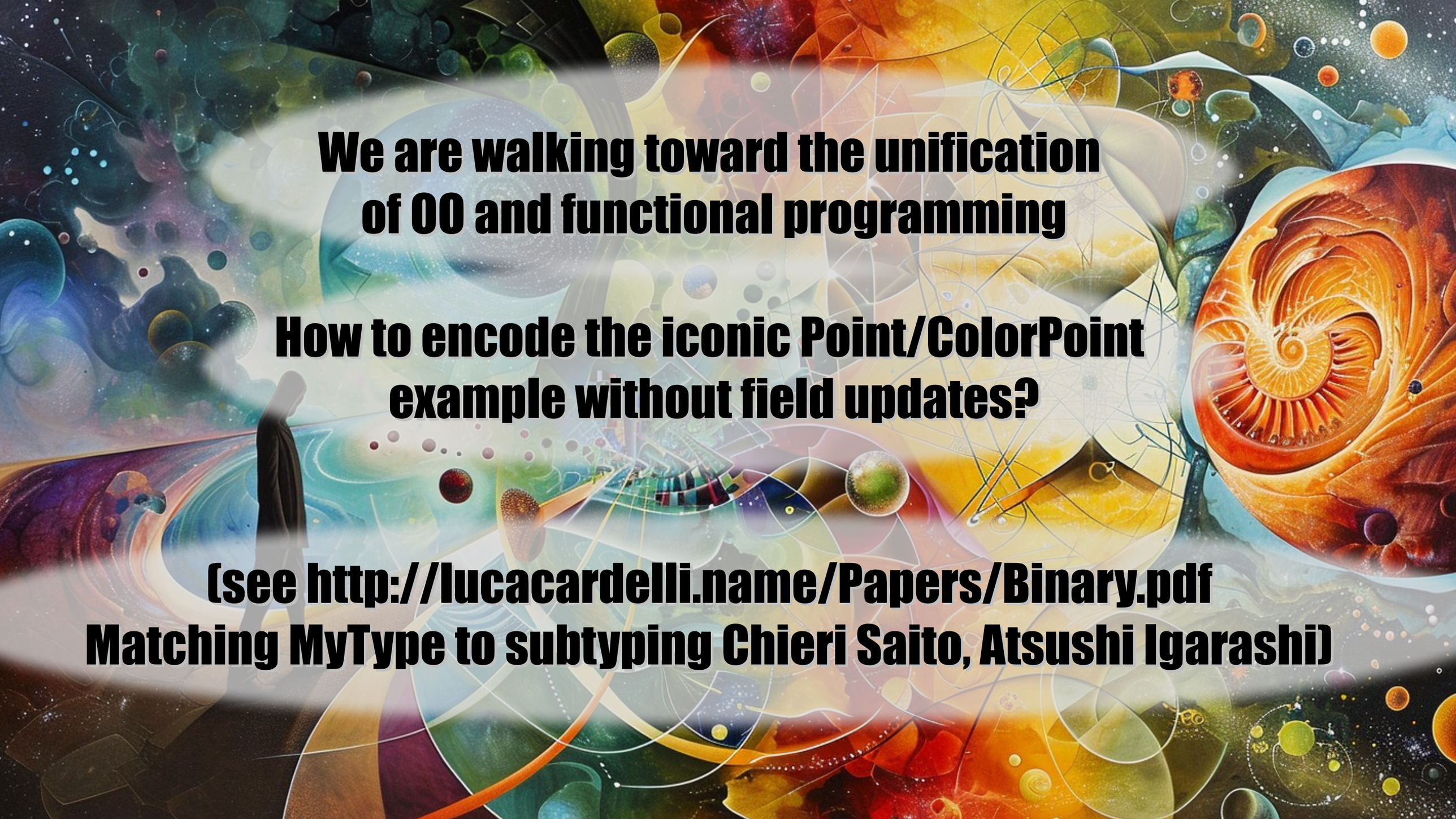
Withers and the unification of OOP and FP

(work in progress)


We are walking toward the unification
of OO and functional programming
How to encode the iconic Point/ColorPoint
example without field updates?
(see http://lucacardelli.name/Papers/Binary.pdf
Matching MyType to subtyping Chieri Saito, Atsushi Igarashi)

I’m starting to think this is like the expression problem because:

- many possible solutions
- all kind of unsatisfactory
- different kinds of methods may surprisingly not be supported

Set up:

```
interface Point{
  int x();
  int y();
  Point withX(int x);
  Point withY(int y);
  String id(); //example method showing overriding on various kinds of points
  default Point times(int r){return this
    .withX( this.x() * r )   //example method body using withers to return a 'Point'
    .withY( this.y() * r );  //We want not to duplicate this body in 'CPoint'
  }
  default Point max(int x){//example method body using withers and occasionally
    if ( this.x() > x ){ return this; }//returning 'this'
    return this.withX(x);
    }
  }
record Point1(int x, int y) implements Point{//example implementations of points
  public Point1 withX(int x){ return new Point1(x,this.y()); }//ideally, withX/Y could
  public Point1 withY(int y){ return new Point1(this.x(),y); }//be auto-generated
  public String id(){ return "Point1"; }
}
record Point2(int x, int y) implements Point{//We could also use anonymous classes
  public Point2 withX(int x){ return new Point2(x,this.y()); }//!
  public Point2 withY(int y){ return new Point2(this.x(),y); }//!
  public String id(){ return "Point2"; }
}
```

Set up:

```
interface CPoint extends Point{
  String color();
  CPoint withColor(String c);
  CPoint withX(int x);//return type refinement
  CPoint withY(int y);//could it be autogenerated? No record here

}
record CPoint1(int x, int y,String color) implements CPoint{
  public CPoint withX(int x){ return new CPoint1(x,this.y(),this.color()); }//!
  public CPoint withY(int y){ return new CPoint1(this.x(),y,this.color()); }//!
  public CPoint withColor(String c){ return new CPoint1(this.x(),this.y(),color); }//!
  public String id(){ return "CPoint1"; }
}
```

Set up:

```
interface CPoint extends Point{
  String color();
  CPoint withColor(String c);
  CPoint withX(int x);//return type refinement
  CPoint withY(int y);//could it be autogenerated? No record here

}
record CPoint1(int x, int y,String color) implements CPoint{
  public CPoint withX(int x){ return new CPoint1(x,this.y(),this.color()); }//!
  public CPoint withY(int y){ return new CPoint1(this.x(),y,this.color()); }//!
  public CPoint withColor(String c){ return new CPoint1(this.x(),this.y(),color); }//!
  public String id(){ return "CPoint1"; }
}

public class Example {
  public static void main(String[] a){
    Point p= new Point1(1, 2);//or Point2
    p = p.withX(0);
    p = p.times(5);//all good
    CPoint cp= new CPoint1(1, 2, "red");
    cp = cp.withX(3);//Works, but directly overridden
    cp = cp.times(4);//Type error: 'times' returns a Point
  }    //We can not do code reuse involving calling the withers.
}      //But with setters, code reuse would be no problem. Is this a limitation of FP?
```

Idea: use generics

```
interface Point<S>{
  int x();
  int y();
  S withX(int x);
  S withY(int y);

  String id();

  default S times(int r){return this
    .withX(this.x()*r)//ok
    .withY(this.y()*r);//does S has a withY?
  }
  default S max(int x){
    if(this.x()>x){ return this; }
    return this.withX(x);
  }
}

record Point1(int x, int y) implements Point<Point1>{
  public Point1 withX(int x){ return new Point1(x,this.y()); }//!
  public Point1 withY(int y){ return new Point1(this.x(),y); }//!
  public String id(){ return "Point1"; }
}
```

Idea: use generics

```
interface Point<S extends Point<S>>{
  int x();
  int y();
  S withX(int x);
  S withY(int y);

  String id();

  default S times(int r){return this
    .withX(this.x()*r)//ok
    .withY(this.y()*r);//does S has a withY? Now it does!
  }
  default S max(int x){
    if(this.x()>x){ return this; }
    return this.withX(x);
  }
}

record Point1(int x, int y) implements Point<Point1>{
  public Point1 withX(int x){ return new Point1(x,this.y()); }//!
  public Point1 withY(int y){ return new Point1(this.x(),y); }//!
  public String id(){ return "Point1"; }
}
```

Idea: use generics

```
interface Point<S extends Point<S>>{
  int x();
  int y();
  S withX(int x);
  S withY(int y);

  String id();

  default S times(int r){return this
    .withX(this.x()*r)
    .withY(this.y()*r);
  }
  default S max(int x){
    if(this.x()>x){ return this; }//Can you spot the error here?
    return this.withX(x);
  }
}

record Point1(int x, int y) implements Point<Point1>{
  public Point1 withX(int x){ return new Point1(x,this.y()); }//!
  public Point1 withY(int y){ return new Point1(this.x(),y); }//!
  public String id(){ return "Point1"; }
}
```

Idea: use generics

```
interface Point<S extends Point<S>>{
  int x();
  int y();
  S withX(int x);
  S withY(int y);

  String id();

  default S times(int r){return this
    .withX(this.x()*r)
    .withY(this.y()*r);
  }
  default S max(int x){
    if(this.x()>x){ return this; }//Can you spot the error here?
    return this.withX(x);//we can not use Point<S> instead of S in the results,
  } //we need S in times/max to be able to reuse its body for both Point/CPoint
}

record Point1(int x, int y) implements Point<Point1>{
  public Point1 withX(int x){ return new Point1(x,this.y()); }//!
  public Point1 withY(int y){ return new Point1(this.x(),y); }//!
  public String id(){ return "Point1"; }
}
```

Idea: use generics

```
interface Point<S extends Point<S>>{
  int x();
  int y();
  S withX(int x);
  S withY(int y);
  S self();
  String id();

  default S times(int r){return this
    .withX(this.x()*r)
    .withY(this.y()*r);
  }
  default S max(int x){ //the 'self' method solves this.
    if(this.x()>x){ return this.self(); }
    return this.withX(x);//we can not use Point<S> instead of S in the results,
  } //we need S in times/max to be able to reuse its body for both Point/CPoint
}

record Point1(int x, int y) implements Point<Point1>{
  public Point1 self(){ return this; }//!
  public Point1 withX(int x){ return new Point1(x,this.y()); }//!
  public Point1 withY(int y){ return new Point1(this.x(),y); }//!
  public String id(){ return "Point1"; }
}
```

Usage

```
interface Point<S extends Point<S>>{
  ...x/y/withX(int x)/withY(int y)/self/id
  default S times(int r){...}
  default S max(int x){...}
}
record Point1(int x, int y) implements Point<Point1>{
  ..self,withX,withY//!
  public String id(){ return "Point1"; }
}
interface CPoint<S extends CPoint<S>> extends Point<S>{
  String color();
  S withColor(String c);
}
record CPoint1(int x, int y,String color) implements Cpoint<CPoint1>{
  ..self,withX,withY,withColor//!
  public String id(){ return "CPoint1"; }
}
...
  public static void main(String[] a){
    Point<?> p= new Point1(1, 2);//Ugly, all types use <?> now
    p = p.withX(0);
    p = p.times(5);
    CPoint<?> cp= new CPoint1(1, 2, "red");
    cp = cp.withX(3);
    cp = cp.times(4);//But it works!
  }
```

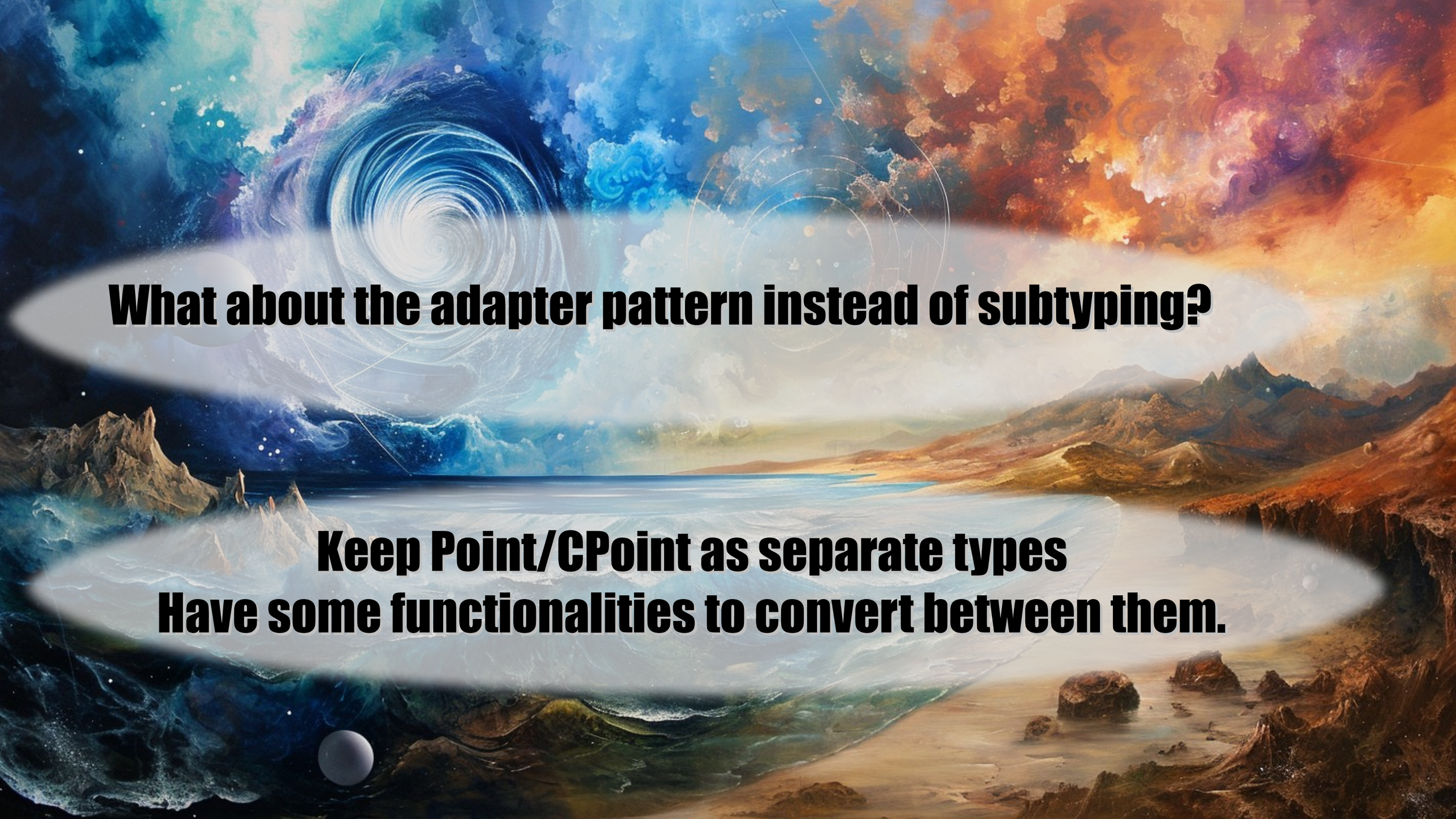
Extension: Diff method

```
interface Point<S extends Point<S>>{
...x/y/withX(int x)/withY(int y)/self/id
  default S times(int r){...}
  default S max(int x){…}
  default String diff(S other){
    return "(" + this.x() + "/" + other.x() + "," + this.y() + "/" + other.y() + ")";
  }
}
interface CPoint<S extends CPoint<S>> extends Point<S>{
  String color();
  S withColor(String c);
  default String diff(S other){//Overridden to print the full difference
    return "(" + this.x() + "/" + other.x() + "," + this.y() + "/" + other.y() + ","
      + this.color() + "/" + other.color() + ")";
  }
}
...
  public static void main(String[] a){
    Point<?> p= new Point1(1, 2);
    CPoint<?> cp= new CPoint1(1, 2, "red");
    capture(p);//can call diff by using wildcard capture!
    capture(cp);
  }
  public static <X extends Point<X>>
  void capture(Point<X> p){
    Point<X> p1= p.withX(10);
    System.out.println(p.diff(p1.self()));
  }
```

This works, but it uses the most sophisticated features of the language.

I argue that if the functional Point / Color Point example is much harder to teach that the mutable version, we do not have a good unification of OOP and FP

We could make it ‘look good’ superficially, by auto-generating many things, and assuming a first generic parameter on everything with the right shape, so we can write ‘Point’ but we mean Point<?> logically. Would this be a solution, or is it just hiding the dust?


What about the adapter pattern instead of subtyping?
Keep Point/CPoint as separate types
Have some functionalities to convert between them.

```
interface Point{
  int x();  int y();  Point withX(int x);  Point withY(int y);
  String id();
  default Point times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  default Point max(int x){
    if(this.x()>x){ return this; }
    return this.withX(x);
  }
}
```

```
interface Point{
  int x();  int y();  Point withX(int x);  Point withY(int y);
  String id();
  default Point times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  default Point max(int x){
    if(this.x()>x){ return this; }
    return this.withX(x);
  }
}
interface CPoint{//Note: does not implement Point
  int x();  int y();  String color();
  CPoint withX(int x);  CPoint withY(int y);  CPoint withColor(String c);
  String id();
  default CPoint withPoint(Point p){ return this.withX(p.x()).withY(p.y()); }
  default Point toPoint(){..}

  default CPoint times(int r){
    return this.withPoint(this.toPoint().times(r)); //first attempt
  }
  default CPoint max(int x){
    return this.withPoint(this.toPoint().max(x));//first attempt
  }
}
```

```
interface Point{
  int x();  int y();  Point withX(int x);  Point withY(int y);
  String id();
  default Point times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  default Point max(int x){
    if(this.x()>x){ return this; }
    return this.withX(x);
  }
}
interface CPoint{//..
  String id();
  default CPoint times(int r){ return this.withPoint(this.toPoint().times(r)); }
  default CPoint max(int x){ return this.withPoint(this.toPoint().max(x)); }

  default CPoint withPoint(Point p){ return this.withX(p.x()).withY(p.y()); }
  default Point toPoint(){ return new Point1(this.x(), this.y()); }
}//returning a Point1 every time is wrong.
 //asking every Cpoint to override toPoint also looks wrong.
```

```
interface Point{..
  default Point times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  ..}

interface CPoint{..
  default CPoint times(int r){ return this.withPoint(this.toPoint().times(r)); }

  default CPoint withPoint(Point p){ return this.withX(p.x()).withY(p.y()); }

  default Point toPoint(){//We can use the adapter pattern!
    CPoint self = this;
    return new Point(){
      public int x(){ return self.x(); }
      public int y(){ return self.y(); }
      public Point withX(int x){ return self.withX(x).toPoint(); }
      public Point withY(int y){ return self.withY(y).toPoint(); }
      public String id(){ return self.id(); }
      public Point times(int r){ return self.times(r).toPoint(); }
      public Point max(int x){ return self.max(x).toPoint(); }
    };
  }
}
//Can you spot the problem?
//stack overflow times → toPoint → times..
```

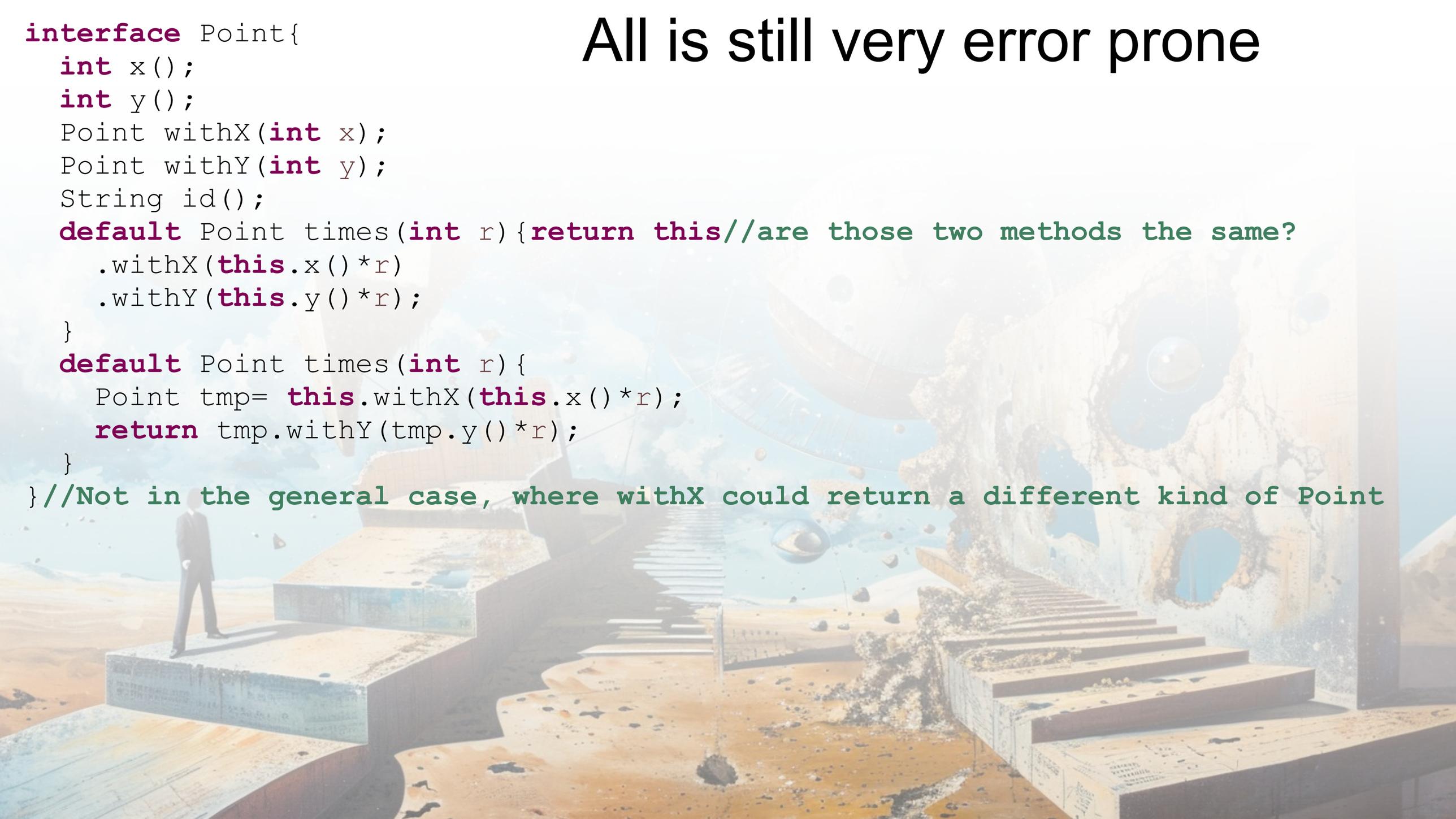
```
interface Point{..
  default Point times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  ..}

interface CPoint{..
  default CPoint times(int r){ return this.withPoint(this.toPoint().times(r)); }

  default CPoint withPoint(Point p){ return this.withX(p.x()).withY(p.y()); }
//withPoint is also wrong since it is keeping the 'id' behavior of the initial CPoint
//not the 'id' behavior of the result of 'times'
//What if there is a special kind of CPoint that overrides times to return a CPoint with
//a different 'id'?
```

```
interface Point{//Interlocked adapter pattern?
  int x(); int y();   Point withX(int x);  Point withY(int y);
  String id();
  default Point times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  default Point max(int x){ .. }
  default CPoint toCPoint(CPoint other){
    Point self = this;
    return new CPoint(){
      public int x(){ return self.x(); }
      public int y(){ return self.y(); }
      public CPoint withX(int x){ return self.withX(x).toCPoint(other); }
      public CPoint withY(int y){ return self.withY(y).toCPoint(other); }
      public String color(){return other.color();}
      public CPoint withColor(String c){ return self.toCPoint(other.withColor(c)); }
      public String id(){ return self.id(); }
      public CPoint times(int r){ return self.times(r).toCPoint(other); }
      public CPoint max(int x){ return self.max(x).toCPoint(other); }
      };}
  }
}
interface CPoint{..
  default Point toPoint(){//Here toCPoint does the unwrapping
    CPoint self = this;
    return new Point(){..
      public CPoint toCPoint(CPoint other){ return self; }
    };
  }
```


Can you tell I'm growing desperate?

All is still very error prone

```
interface Point{
  int x();
  int y();
  Point withX(int x);
  Point withY(int y);
  String id();
  default Point times(int r){return this//are those two methods the same?
    .withX(this.x()*r)
    .withY(this.y()*r);
  }
  default Point times(int r){
    Point tmp= this.withX(this.x()*r);
    return tmp.withY(tmp.y()*r);
  }
}//Not in the general case, where withX could return a different kind of Point
```



What is the guarantee of ‘withX/times’?

```
interface Point{
  int x();
  int y();
  Point withX(int x);
  Point withY(int y);
  String id();
  default Point times(int r){return this//are those two methods the same?
    .withX(this.x()*r)//on field update, we keep the ‘dynamic type’ of this
    .withY(this.y()*r);//Do we? What about python
  }
  default Point times(int r){
    Point tmp= this.withX(this.x()*r);
    return tmp.withY(tmp.y()*r);
  }
}//Not in the general case, where withX could return a different kind of Point
```

Other ideas/options

- Super expressive structural types (co-induction)
  - Not my strong suite
- SelfType/This/Mytype/Self
  - This avoid the times example error before. But… is this killing oo?
- Value based languages
  - Another version where the ‘withX’ is statically guaranteed to return the same dynamic type of the receiver instead of allowing for subtypes.

The ‘?’ solution is not ‘MyType’

```
interface Point<S extends Point<S>>{
  int x();  int y();  S withX(int x);  S withY(int y);  S self();
  String id();
  default S times(int r){ return this.withX(this.x()*r).withY(this.y()*r); }
  default S max(int x){..}
  default String diff(S other){
    return "("+this.x()+"/"+other.x()+","+this.y()+"/"+other.y()+")";
  }
}
record Point2(int x, int y) implements Point<Point2>{
  public Point2 self(){ return this; }
  public Point2 withX(int x){ return new Point2(x,this.y()); }
  public Point2 withY(int y){ return new Point2(this.x(),y); }
  public String id(){ return "Point2"; }
}
record Point3(int x, int y) implements Point<Point2>{
  public Point2 self(){ return new Point2(x,y); }
  public Point2 withX(int x){ return new Point2(x,this.y()); }
  public Point2 withY(int y){ return new Point2(this.x(),y); }
  public String id(){ return "Point3"; }
}
```

A situation where mutation GIVES a GUARANTEE

Point p=..

At a certain moment, p is exactly a Point1

in the void setters there is no way the type is changed

in the withers, now there is a way to change the type

Point<?> p=..

Point<?> p2=p.withX(3);

The big choice:

- Withers are statically enforced to return the exact type of the receiver (in the sense of dynamic dispatch behaving the same)
  - There will be methods ‘using withers’ that also are statically enforced to return the same exact type
- Withers can return a subtype as usual in any other OO methods
  - More consistent/simpler behavior?

Two forms of subtyping in OO?

- Subtyping as dynamic dispatch can differ between different types of Points
  - This is an extension of FP first class functions: the behavior of calling an int→str function is dynamically dispatched
- Subtyping as feature growth, as between Point and ColorPoint
  - This is more connected with record subtyping

Questions / Discussion