C++ interoperability with memory-safe languages

Gábor Horváth

Improving safety

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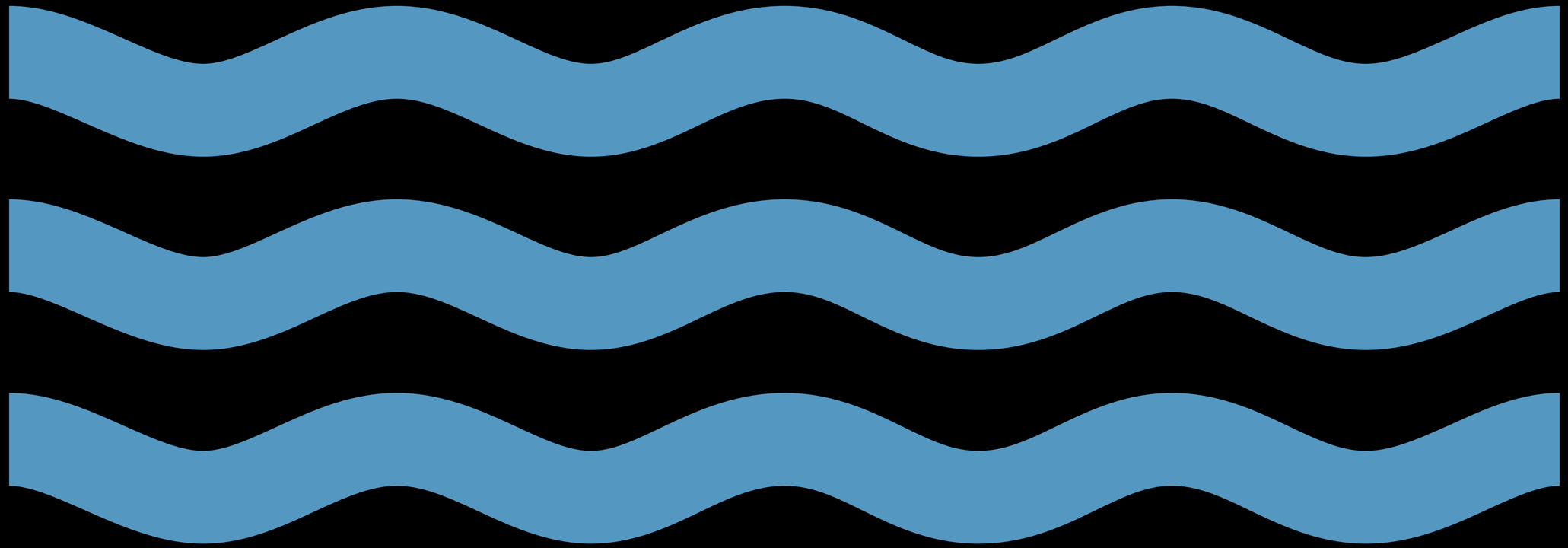

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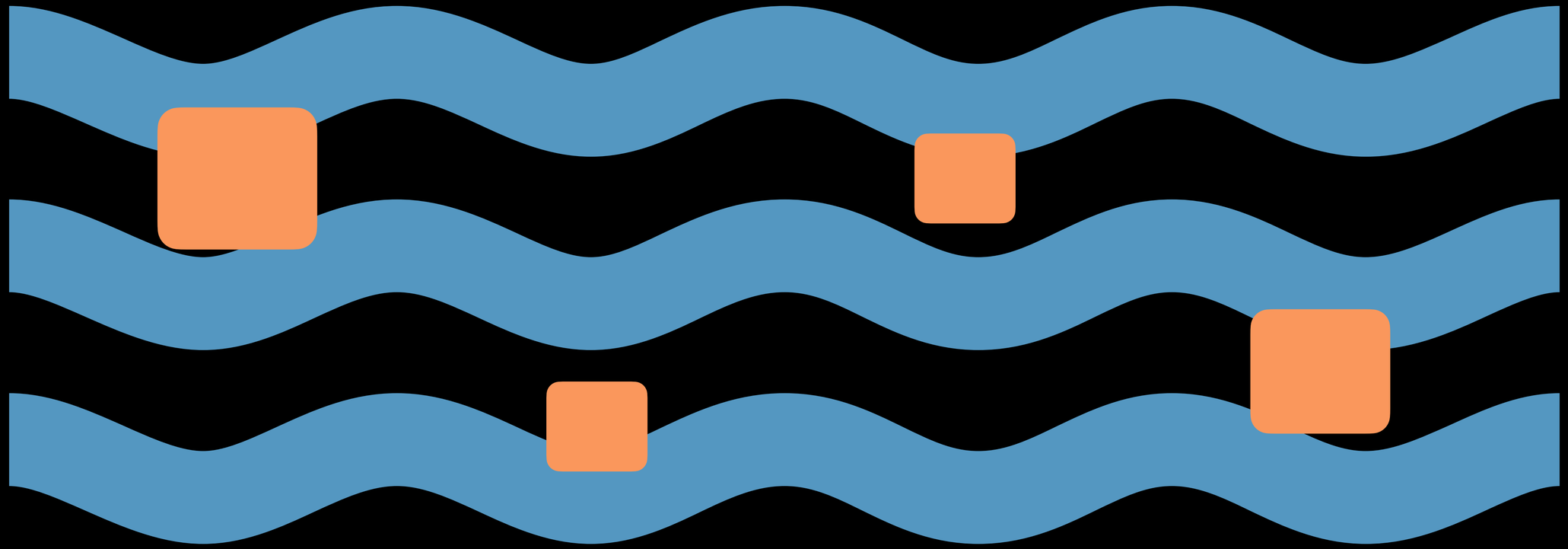

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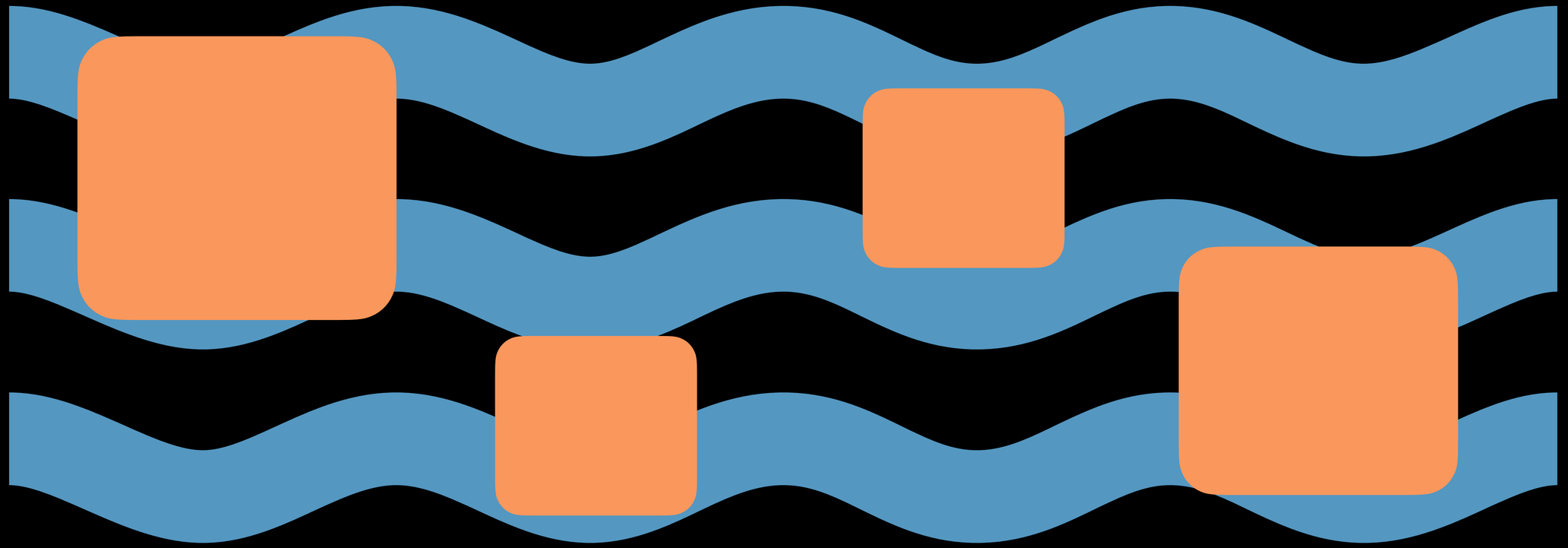

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Dimensions of memory safety

Lifetime safety

- Lifetime annotations

Bounds safety

- Bounds safety annotations, hardened libc++

Type safety

- Typed allocation, type sanitizer

Initialization safety

- Automatic variable initialisation, memory sanitizer

Thread safety

- Thread safety analysis, thread sanitizer

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auto it = vec.begin();
vec.push_back(42);
*it += 1729;
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What is lifetime safety?

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auto it = vec.begin();
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```
// C++
std::vector<int> getVecOfInt();

// Swift
let vec = getVecOfInt()
let begin = vec.__beginUnsafe()
let val = begin.pointee
```

What is lifetime safety?

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C and C++ APIs are missing lifetime information

Adding the missing information has a huge design space

Different tradeoffs for the ease of adoption

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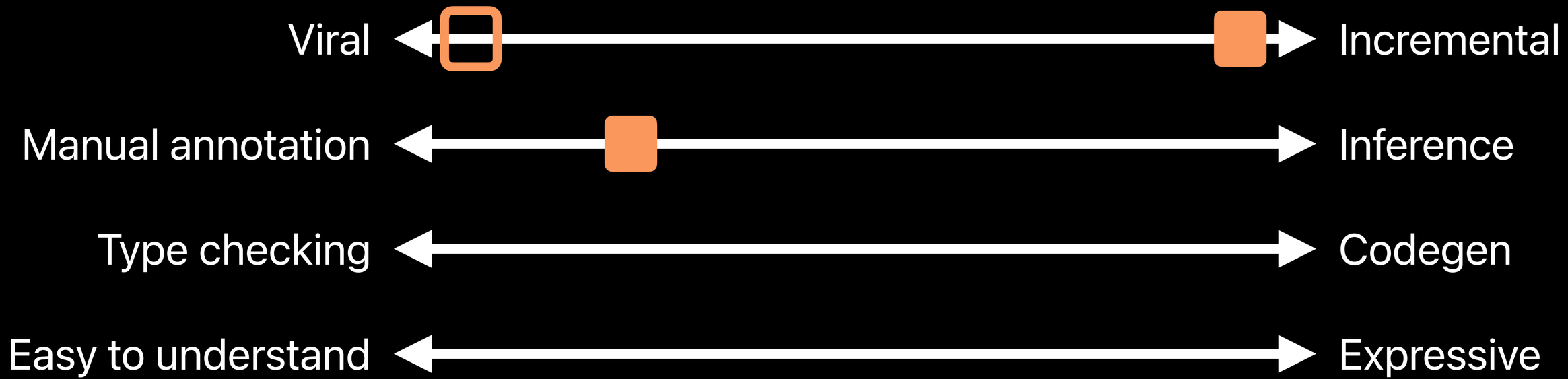

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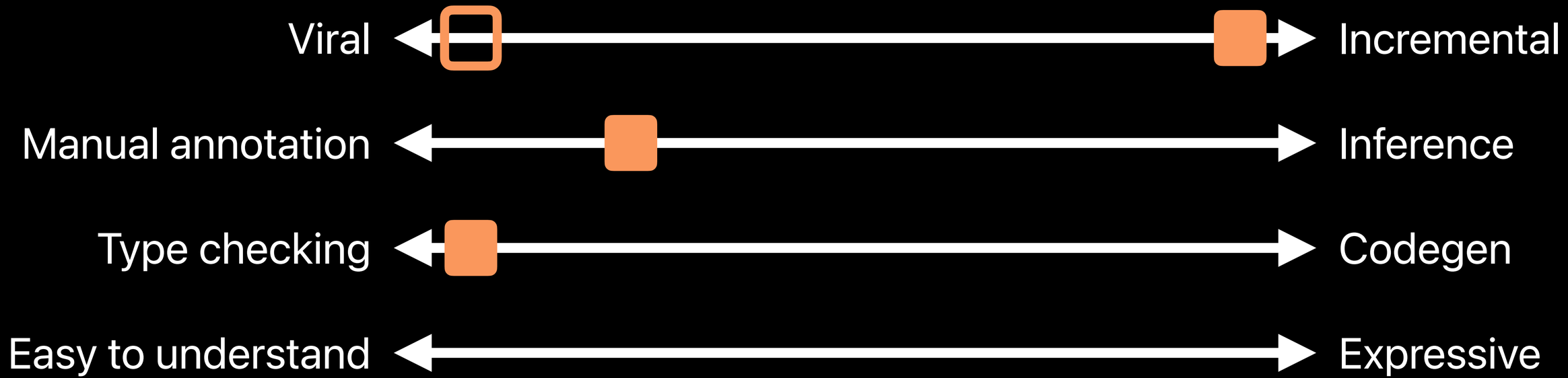

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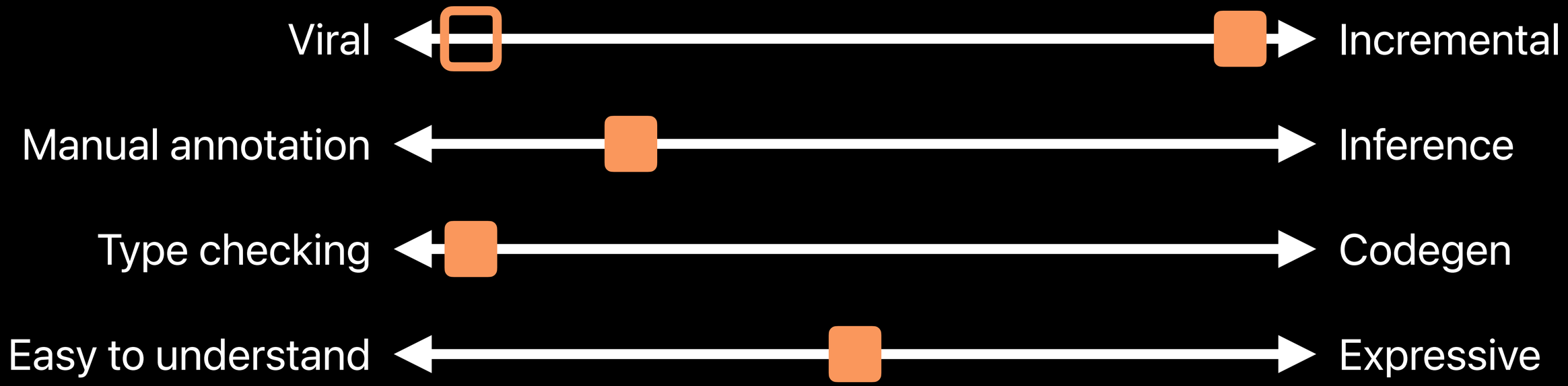

Annotating lifetimes in Clang

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const char* p = std::string("Hello").data();
const char* q = std::string_view("Hello").data();
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```
struct string {
   const char* data() const [[clang::lifetimebound]];
};
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clang-7

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              std::set<std::string_view>& s);
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clang-20

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Attribute for lifetime constraints on types

```
class                       StringRef {
public:
    StringRef() : ptr(nullptr), len(0) {}

    std::string toString() const;
private:
    const char* ptr;
    size_t len;
};

std::string normalize(const std::string& path);

// The path needs to be normalized.
StringRef fileName(const std::string& path);
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```
warning: the returned type 'StringRef' is annotated as a reference
 type; its lifetime dependencies must be annotated
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Attribute for lifetime constraints on types

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class SWIFT_NONESCAPABLE StringRef {
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Attribute for lifetime constraints on types

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// The path needs to be normalized.
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```

```
func getFileName(_ path: borrowing std.string) -> StringRef {
    let normalizedPath = normalize(path)
    return fileName(normalizedPath)
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class                       StringRef {
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```

```
warning: expression uses unsafe constructs but is not marked with 'unsafe'
    return fileName(normalizedPath)
           ^~~~~~~~~~~~~~~~~~~~~~~~
           unsafe
note: reference to global function 'fileName' involves unsafe type 'StringRef'
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};

std::string normalize(const std::string& path);

// The path needs to be normalized.
StringRef fileName(const std::string& path);
```

```
warning: the returned type 'StringRef' is annotated as non-escapable;
 its lifetime dependencies must be annotated
    :     return fileName(normalizedPath)
    : }
```

Consuming annotations from Swift

```
std::string normalize(const std::string& path);

// The path needs to be normalized.
StringRef fileName(const std::string& path [[clang::lifetimebound]]);
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func getFileName(_ path: borrowing std.string) -> StringRef {
    let normalizedPath = normalize(path)
    return fileName(normalizedPath)
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```

```
error: lifetime-dependent value escapes its scope
    return fileName(normalizedPath)
           ^
note: it depends on the lifetime of variable 'normalizedPath'
    let normalizedPath = normalize(path)
        ^
note: this use causes the lifetime-dependent value to escape
    return fileName(normalizedPath)
    ^
```

Annotating templated types

```
std::vector<StringRef>   g(StringRef);
std::vector<std::string> h(StringRef);
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SWIFT_ESCAPABLE_IF(T)
template<class T, ...>
struct vector;
```

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New

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SWIFT_ESCAPABLE_IF(T)
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struct vector;
```

Annotating independence

```
StringRef capital(StringRef country                    ) {
    if (country == "Germany") {
        return "Berlin";
    } else if (...) {
        // ...
    }
    return "Unknown";
}
```

Annotating independence

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Annotating independence

```
[[clang::lifetime_immortal]]
StringRef capital(StringRef country [[clang::noescape]]) {
    if (country == "Germany") {
        return "Berlin";
    } else if (...) {
        // ...
    }
    return "Unknown";
}
```

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```

Incremental annotations

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Supports incremental adoption

```
int* id(int* p) { return p; }

int* f(int* p [[lifetimebound]]) {
  return id(p);
}
```

Incremental annotations

Supports incremental adoption

Not exhaustive

```
int* id(int* p) { return p; }

int* f(int* p [[lifetimebound]]) {
  return id(p);
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const int& min(const int& lhs [[lifetimebound]],
               const int& rhs);
```

Incremental annotations

Supports incremental adoption

Not exhaustive

Limited expressivity,
lowest common denominator

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int* id(int* p) { return p; }

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int* first(std::pair<int*, int*> p);
```

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Limited expressivity,
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Best effort on the C++ side, fully enforced in the safe language

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int* f(int* p [[lifetimebound]]) {
  return id(p);
}

const int& min(const int& lhs [[lifetimebound]],
               const int& rhs);

int* first(std::pair<int*, int*> p);

int* id(int* p [[lifetimebound]]) { return p; }
int* p = nullptr;
{
    int a;
    p = id(&a);
}
```

Summary

Express lifetime contracts not available in the type system

Existing Clang features with minimal extensions make interop possible

C++ and memory-safe language both benefit from the annotations

Easy adoption is crucial

- Start growing the islands of safe code as soon as possible
- No friction/push back from C++ code owners
- When full contract checking is a must, use a safe language