C++20: The small things

Version 1.3

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@timur_audio

MeetingC++
14 November 2019

IS schedule

The following is the current schedule for the C++ IS, approved by WG21 unanimous consent in Jacksonville (2018-03).

2017.2 – Toronto	First meeting of C++20
2017.3 – Albuquerque	*Try to front-load "big" language features including ones with broad library impact* *(incl. try to merge TSes here)*
2018.1 – Jacksonville	
2018.2 – Rapperswil	
2018.3 – San Diego	*EWG: Last meeting for new C++20 language proposals we haven't seen before* *EWG → LEWG: Last meeting to approve C++20 features needing library response* *LEWG: Focus on progressing papers on how to react to new language features*
2019.1 – Kona	** → CWG,LWG: Last meeting to send proposals to wording review (incl. TS merges)* C++20 design is feature-complete
2019.2 – Cologne	CWG+LWG: Complete CD wording EWG+LEWG: Working on C++23 features + CWG/LWG design clarification questions C++20 draft wording is feature complete, **start CD ballot**
2019.3 – Belfast	CD ballot comment resolution
2020.1 – Prague	CD ballot comment resolution C++20 technically finalized, **start DIS ballot**

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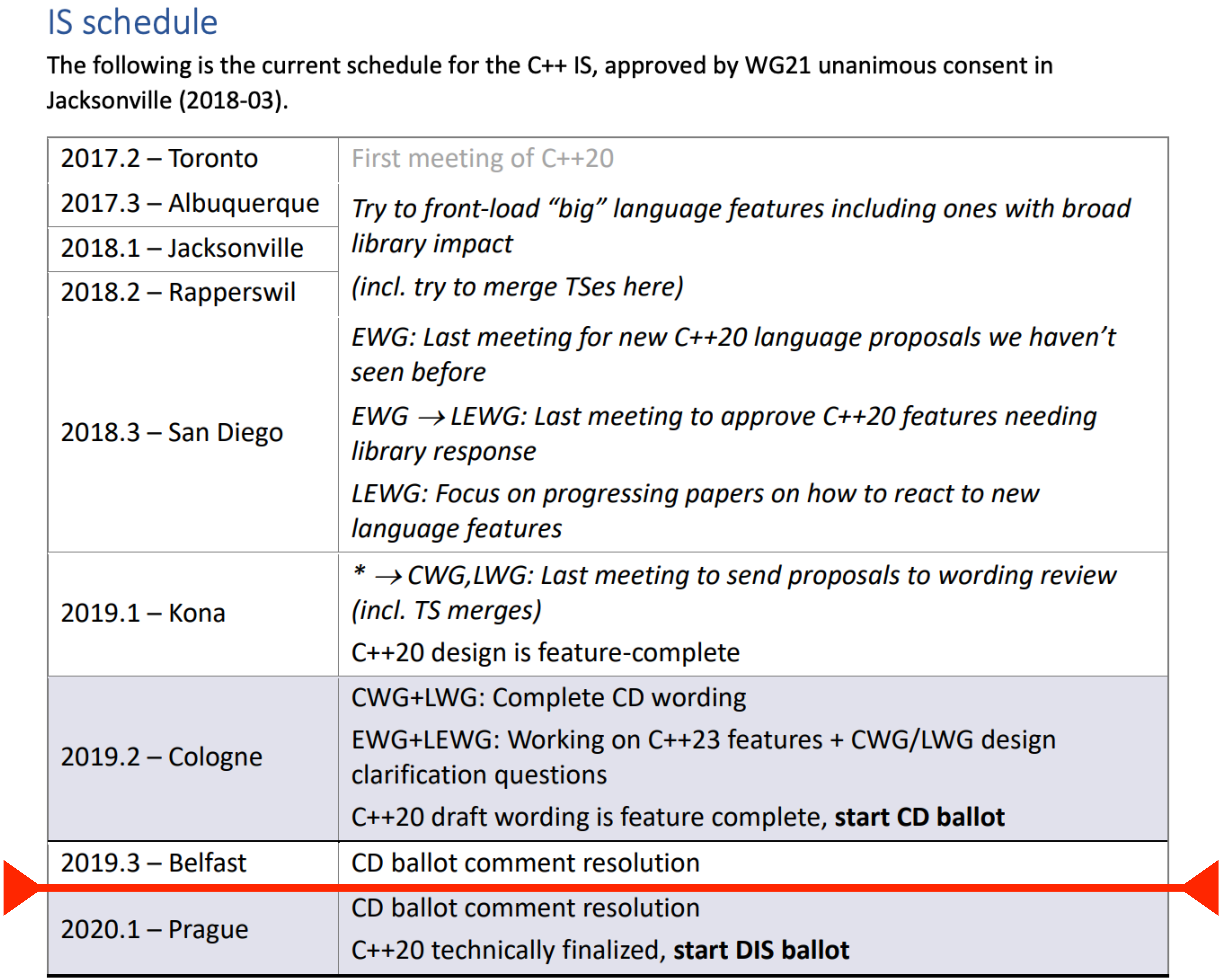

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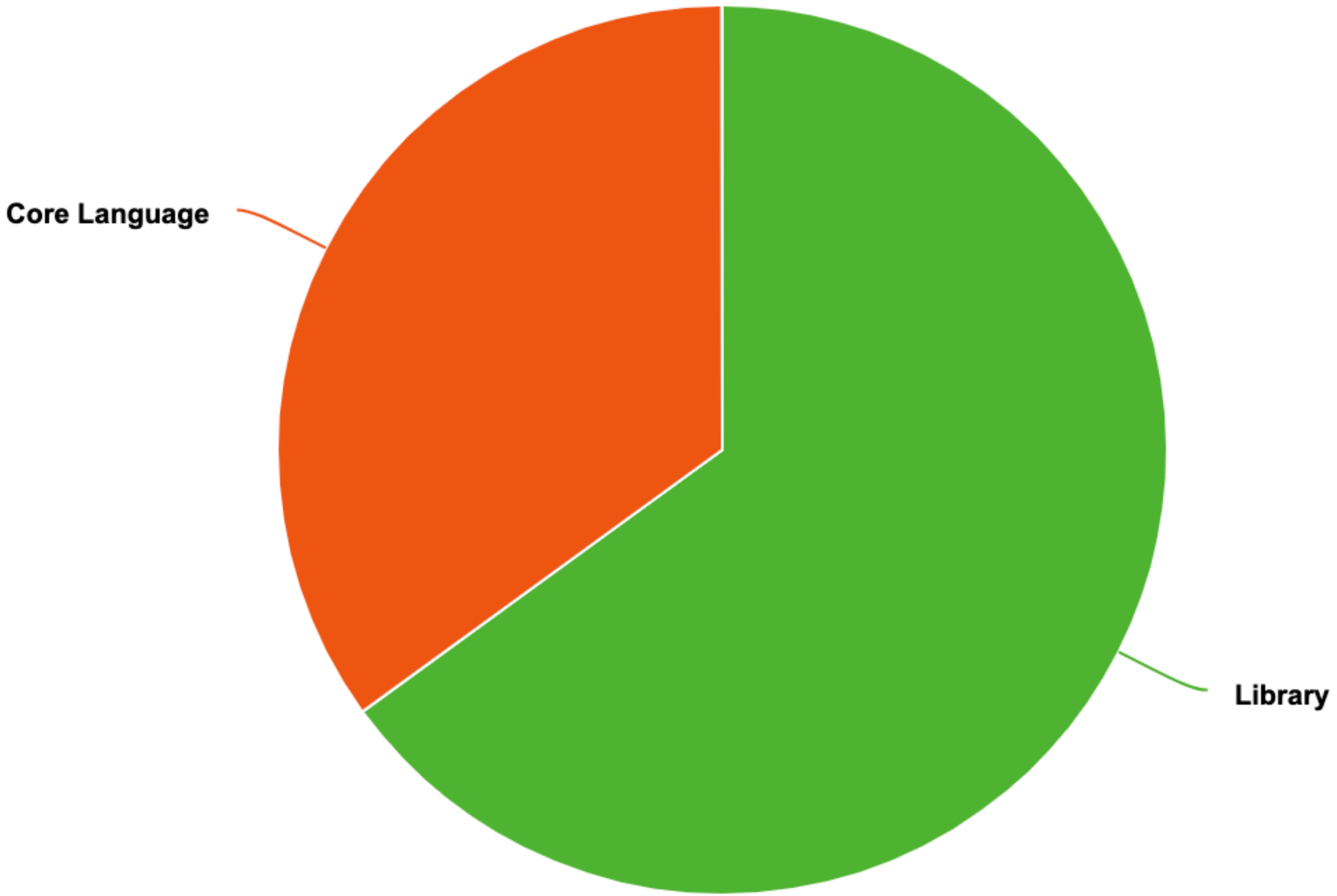
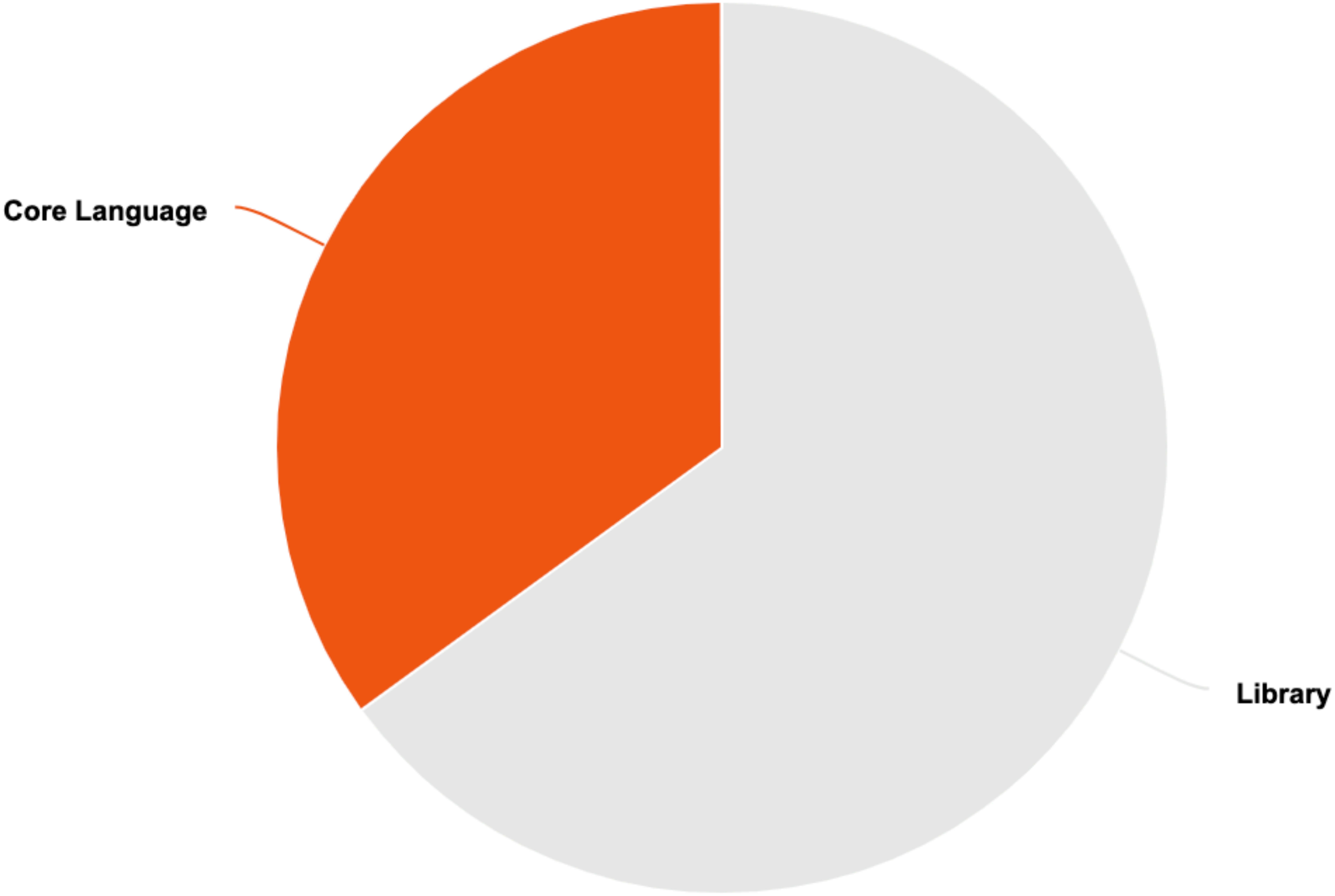
we are here


Core Language
Library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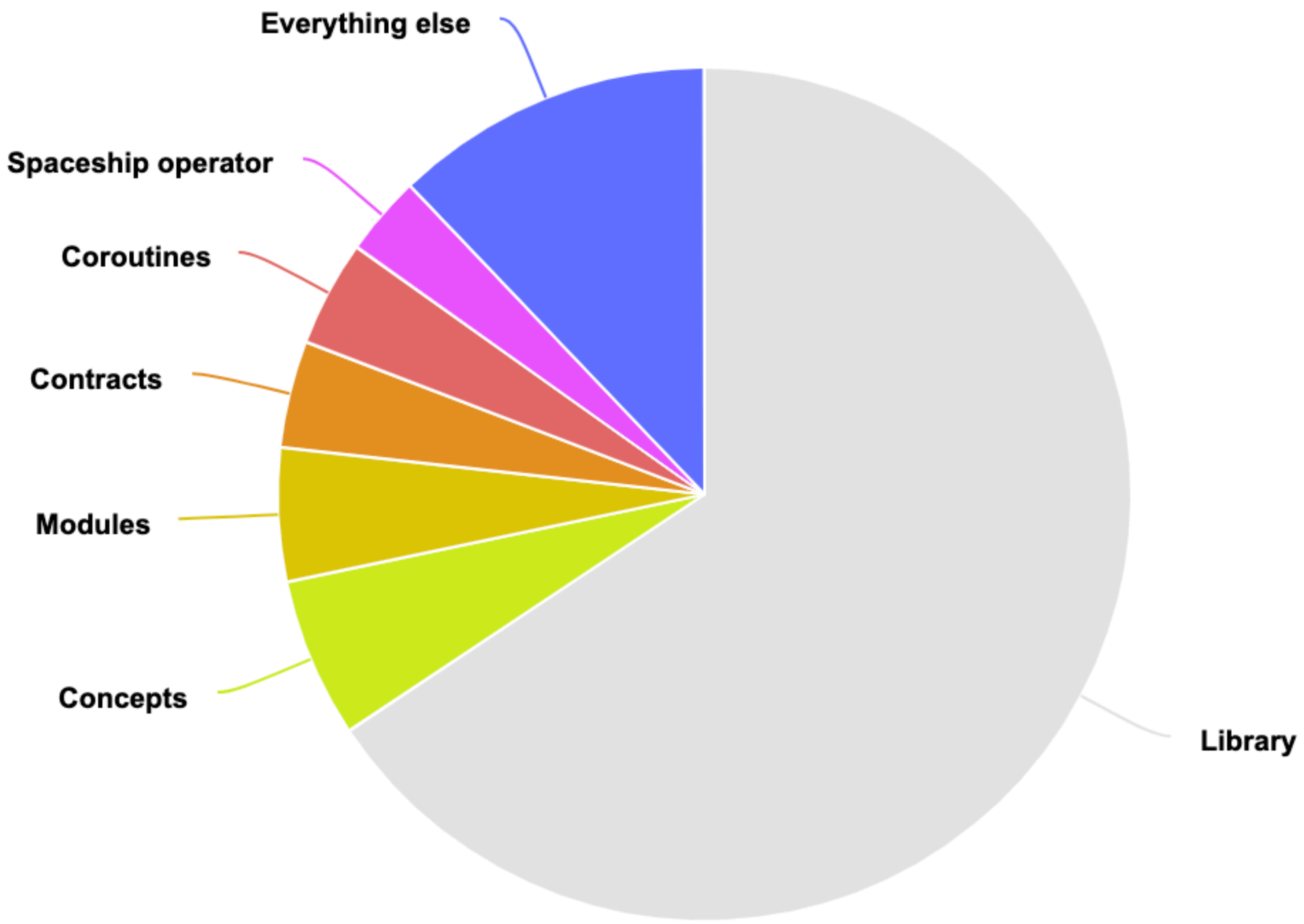
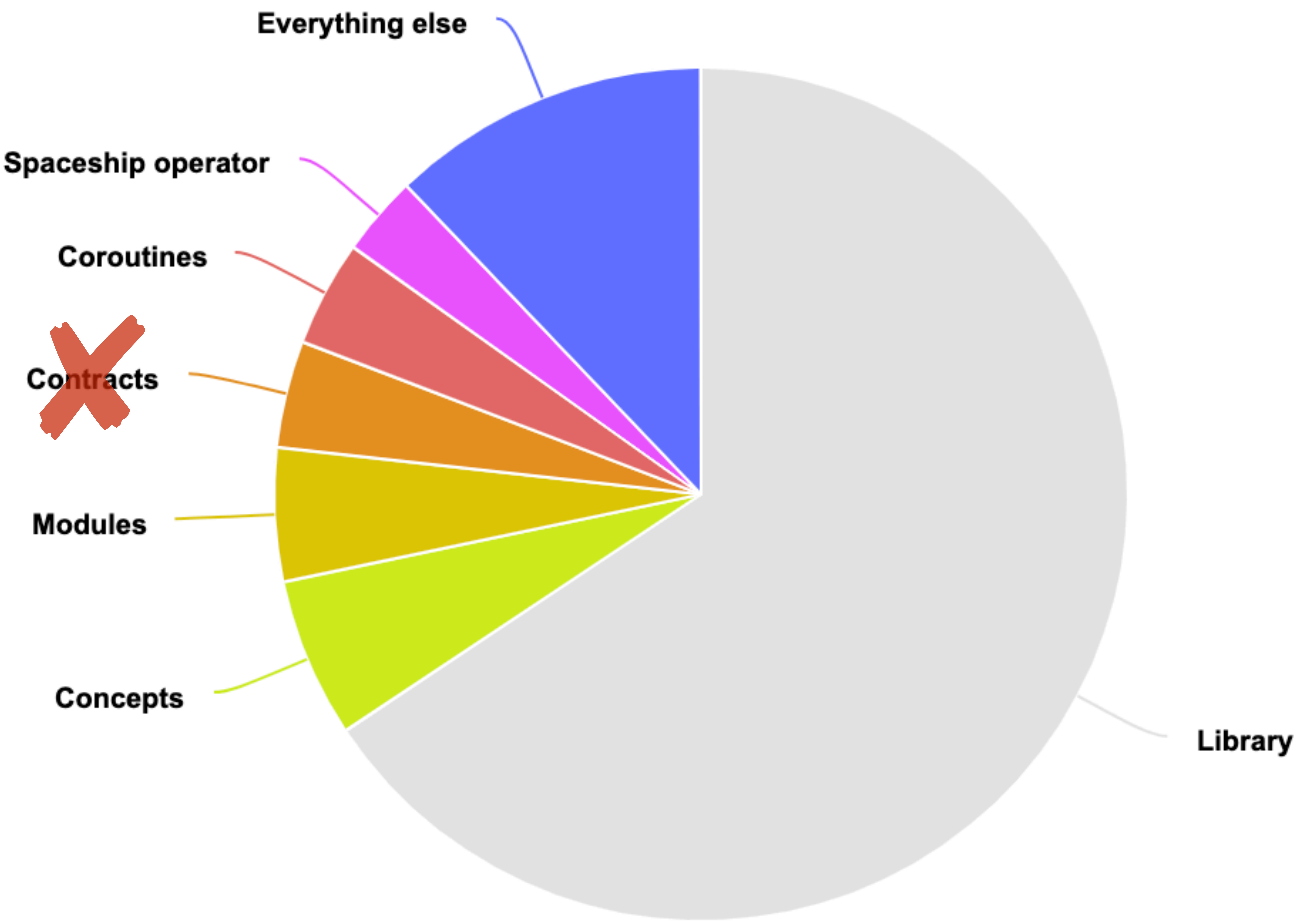

Everything else
Spaceship operator
Coroutines
Contracts
Modules
Concepts
Library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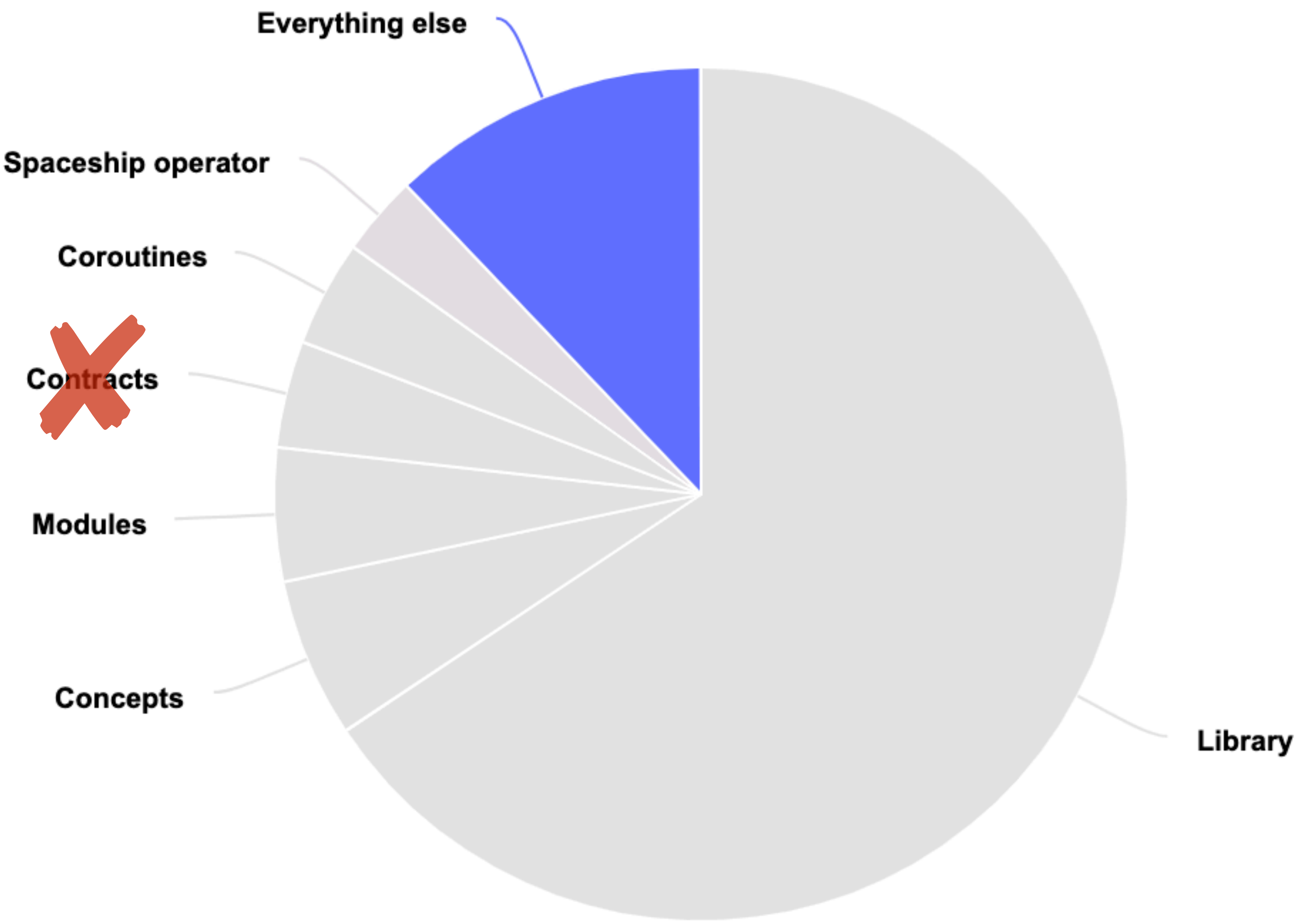
Everything else
Spaceship operator
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1 Initialisation

2 Structured bindings

3 Lambdas

4 Templates

5 constexpr

6 Miscellaneous

1 Initialisation

2 Structured bindings

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Aggregates

```
struct Widget {
  int a;
  bool b;
  int c;
};
```

Aggregates

```cpp
struct Widget {
  int a;
  bool b;
  int c;
};

int main() {
  Widget widget = {3, true};
}
```

Designated initialisers

```
struct Widget {
  int a;
  bool b;
  int c;
};

int main() {
  Widget widget{.a = 3, .c = 7};
}
```

Designated initialisers

```
struct Widget {
  int a;
  bool b;
  int c;
};

int main() {
  Widget widget{.a = 3, .c = 7};
}
```

Only for aggregate types.

C compatibility feature.

Works like in C99, except:

- not out-of-order

```
Widget widget{.c = 7, .a = 3} // Error
```

- not nested

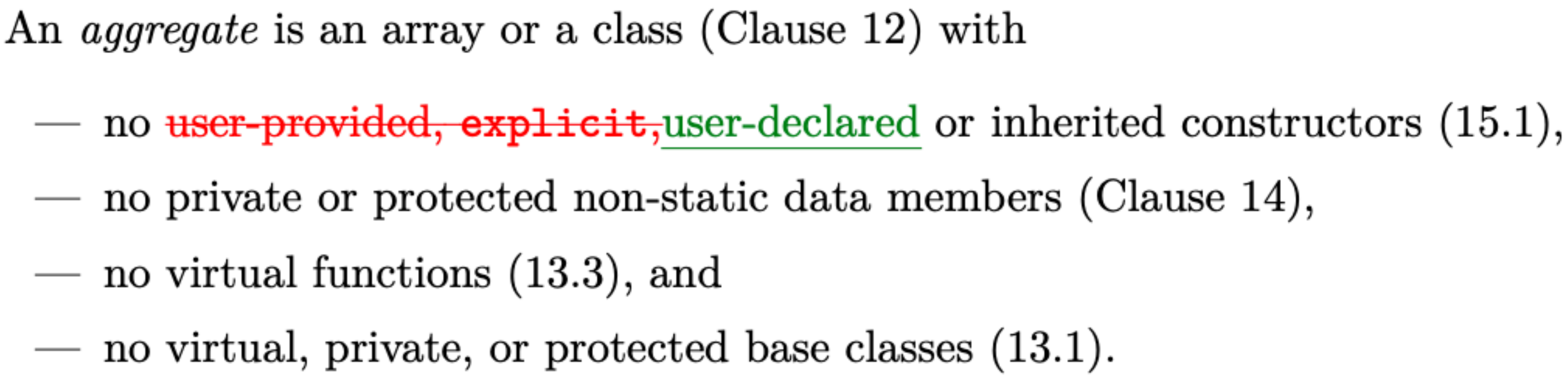
```
Widget widget{.c.e = 7} // Error
```

- not mixed with regular initialisers

```
Widget widget{.a = 3, 7} // Error
```

- not with arrays

```
int arr[3]{.[1] = 7} // Error
```



An *aggregate* is an array or a class (Clause 12) with

— no ~~user-provided, explicit,~~user-declared or inherited constructors (15.1),

— no private or protected non-static data members (Clause 14),

— no virtual functions (13.3), and

— no virtual, private, or protected base classes (13.1).

Aggregates can no longer declare constructors

Aggregates can no longer declare constructors

```
struct Widget {
  Widget() = delete;
};

Widget w1;    // Error
```

Aggregates can no longer declare constructors

```
struct Widget {
  Widget() = delete;
};

Widget w1;    // Error
Widget w2{};  // OK in C++17!
```

Aggregates can no longer declare constructors

```
struct Widget {
  Widget() = delete;
};

Widget w1;    // Error
Widget w2{};  // OK in C++17! Will be error in C++20
```

C++17 problems with aggregate initialisation:

- Does not work with macros:

```
assert(Widget(2, 3));   // OK
```

C++17 problems with aggregate initialisation:

- Does not work with macros:

```
assert(Widget(2, 3));   // OK
assert(Widget{2, 3});   // Error: this breaks the preprocessor :(
```

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- Does not work with macros:

```
assert(Widget(2, 3));   // OK
assert(Widget{2, 3});   // Error: this breaks the preprocessor :(
```

- Can’t do perfect forwarding in templates
    - can’t write emplace or make_unique that works for aggregates :(

C++20: Direct-initialisation of aggregates

```cpp
struct Widget {
  int i;
  int j;
};

Widget widget(1, 2);   // will work in C++20!
```

C++20: Direct-initialisation of aggregates

```
struct Widget {
  int i;
  int j;
};

Widget widget(1, 2);   // will work in C++20!
int arr[3](0, 1, 2);    // will work in C++20!
```

C++20: Direct-initialisation of aggregates

```
struct Widget {
  int i;
  int j;
};

Widget widget(1, 2);   // will work in C++20!
int arr[3](0, 1, 2);    // will work in C++20!
```

So in C++20, `(args)` and `{args}` will do the same thing!

Except:

- `()` does not call std::initializer_list constructors
- `{}` does not allow narrowing conversions

constinit

```
struct Colour
{
    Colour(int r, int g, int b) noexcept;
};
```

constinit

```
struct Colour
{
    Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    const Colour red = {255, 0, 0};
}
```

constinit

```
struct Colour
{
    Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    const Colour red = {255, 0, 0};  // dynamic initialisation
}
```

constinit

```
struct Colour
{
    Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    const Colour red = {255, 0, 0};  // dynamic initialisation
}                                     // -> initialisation order fiasco -> UB :(
```

constinit

```
struct Colour
{
    constexpr Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    constexpr Colour red = {255, 0, 0};
}
```

constinit

```
struct Colour
{
    constexpr Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    constexpr Colour red = {255, 0, 0};  // constant initialisation :)
}
```

constinit

```
struct Colour
{
    constexpr Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    Colour backgroundColour = getBackgroundColour();
}
```

constinit

```
struct Colour
{
    constexpr Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    Colour backgroundColour = getBackgroundColour();  // const or dynamic init?
}
```

constinit

```
struct Colour
{
    constexpr Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    constinit Colour backgroundColour = getBackgroundColour();
}
```

constinit

```
struct Colour
{
    constexpr Colour(int r, int g, int b) noexcept;
};

namespace Colours
{
    constinit Colour backgroundColour = getBackgroundColour();
}   // ^^^^^^ only compiles if init happens at compile time :)
```

Range-based for with initialiser

C++17

```
Database getDatabase();


for (auto&& user : getDatabase().getUsers())
{
  registerUser(user);
}
```

Range-based for with initialiser

C++17

```
Database getDatabase();


for (auto&& user : getDatabase().getUsers()) // maybe undefined behaviour!
{
  registerUser(user);
}
```

Range-based for with initialiser

C++17

```
Database getDatabase();

auto db = getDatabase();
for (auto&& user : db.getUsers())
{
  registerUser(user);
}
```

Range-based for with initialiser

C++17

```
Database getDatabase();

{
  auto db = getDatabase();
  for (auto&& user : db.getUsers())
  {
    registerUser(user);
  }
}
```

Range-based for with initialiser

C++20

```
Database getDatabase();


for (auto db = getDatabase(); auto&& user : db.getUsers())
{
  registerUser(user);
}
```

1 Initialisation

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```
struct Widget
{
    int i;
    bool b;
};

auto [a, b] = getWidget();
```

```cpp
struct Widget
{
    int i;
    bool b;
};

auto [a, b] = getWidget();
static [a, b] = getWidget();  // Error in C++17
thread_local [a, b] = getWidget();  // Error in C++17
```

```cpp
struct Widget
{
    int i;
    bool b;
};

auto [a, b] = getWidget();
static [a, b] = getWidget();  // OK in C++20
thread_local [a, b] = getWidget();  // OK in C++20
```

```
struct Widget
{
    int i;
    bool b;
};

auto [a, b] = getWidget();

auto f = [a]{ return a > 0; };  // Error in C++17:
                                // capture ‘a’ does not name a variable
```

```
struct Widget
{
    int i;
    bool b;
};

auto [a, b] = getWidget();

auto f = [a]{ return a > 0; };  // OK in C++20
```

```cpp
struct Widget
{
    int i;
    bool b;
};

auto [a, b] = getWidget();

auto f = [a]{ return a > 0; };  // OK in C++20
                                // copies ‘a’, not the whole object
```

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C++20: pack expansion allowed in lambda init capture

```
template<class F, class... Args>
auto delay_invoke(F f, Args... args) {
    return [f = std::move(f), ...args = std::move(args)]() -> decltype(auto) {
        return std::invoke(f, args...);
    };
}
```

More C++20 lambda features:

- Lambdas are allowed in unevaluated contexts
- Lambdas (without captures) are default-constructible and assignable

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```
decltype([]{})
```

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- Lambdas are allowed in unevaluated contexts
- Lambdas (without captures) are default-constructible and assignable

```
decltype([]{}) f;
```

More C++20 lambda features:

– Lambdas are allowed in unevaluated contexts

– Lambdas (without captures) are default-constructible and assignable

```
class Widget
{
    decltype([]{}) f;
};
```

```
template <typename T>
using MyPtr = std::unique_ptr<
    T, decltype([](T* t) { myDeleter(t); })>;

MyPtr<Widget> ptr;
```

```
template <typename T>
using MyPtr = std::unique_ptr<
    T, decltype([](T* t) { myDeleter(t); })>;

MyPtr<Widget> ptr;

using WidgetSet = std::set<
    Widget,
    decltype([](Widget& lhs, Widget& rhs) { return lhs.x < rhs.x; })>;

WidgetSet widgets;
```

Generic lambdas / functions

```
auto f = [](auto a){
    return a * a;
};
```

Generic lambdas / functions

```
auto f = [](auto a){
    return a * a;
};

auto f(auto a) {   // Generic *functions* - OK since C++20 :)
    return a * a;
}
```

Generic lambdas / functions

```cpp
template <typename T>
void f(std::vector<T> vector) {
    // ...
}
```

Generic lambdas / functions

```
template <typename T>
void f(std::vector<T> vector) {
    // ...
}

// C++20:
auto f = []<typename T>(std::vector<T> vector) {
    // ...
};
```

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Non-type template parameters (NTTPs)

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```cpp
template <int size>
struct Widget
{
    std::array<int, size> a;
};
```

Non-type template parameters (NTTPs)

```
template <int size>
struct Widget
{
    std::array<int, size> a;
};
```

C++20: floating-point NTTPs

```cpp
template <double x>
struct Filter
{
    std::array<double, 2> coefficients = {x, 0.5 * x * x};

    // stuff...
};
```

C++20: class-type NTTPs

```
struct Coefficients
{
    double x;
    double y;
};
```

C++20: class-type NTTPs

```
struct Coefficients
{
    double x;
    double y;
};

template <Coefficients coeffs>
struct Filter
{
    // stuff :)
};
```

C++20: class-type NTTPs

```
struct Coefficients
{
    double x;
    double y;
};

template <Coefficients coeffs>
struct Filter
{
    // stuff :)
};

constexpr Filter<Coefficients{1, 0.125}> f;
```

CTAD

CTAD

```
std::vector v = {1, 2, 3};        // std::vector<int>
```

CTAD

```
std::vector v = {1, 2, 3};       // std::vector<int>

std::tuple t = {42, 0.5, true};  // std::tuple<int, double, bool>
```

CTAD

```
std::vector v = {1, 2, 3};       // std::vector<int>

std::tuple t = {42, 0.5, true};  // std::tuple<int, double, bool>

std::scoped_lock lock(rtmutex);  // std::scoped_lock<std::recursive_timed_mutex>
```

C++20 adds:

– CTAD for aggregates

– CTAD for alias templates

C++17

```
template <typename T, typename U>
struct aggr_pair
{
    T t;
    U u;
};




aggr_pair p = {1, true}; // Error: no deduction candidate found
```

C++17

```cpp
template <typename T, typename U>
struct aggr_pair
{
    T t;
    U u;
};

template <typename T, typename U>
aggr_pair(T, U) -> aggr_pair<T, U>;

aggr_pair p = {1, true}; // OK
```

C++17

```cpp
template <typename T, typename U>
struct aggr_pair
{
    T t;
    U u;
};

template <typename T, typename U>
aggr_pair(T, U) -> aggr_pair<T, U>;

aggr_pair p = {1, true}; // OK
```

C++20

```cpp
template <typename T, typename U>
struct aggr_pair
{
    T t;
    U u;
};




aggr_pair p = {1, true}; // OK
```

```
template<typename... Bases>
struct overloaded : Bases...
{
    using Bases::operator()...;
};
```

C++17

```
template<typename... Bases>
struct overloaded : Bases...
{
    using Bases::operator()...;
};

template<typename... Bases>
overloaded(Bases...) -> overloaded<Bases...>;
```

C++17

C++17

```
template<typename... Bases>
struct overloaded : Bases...
{
    using Bases::operator()...;
};

template<typename... Bases>
overloaded(Bases...) -> overloaded<Bases...>;

overloaded printer = {
    [](auto arg) { std::cout << arg << ' '; },
    [](double arg) { std::cout << std::fixed << arg << ' '; },
    [](const char* arg) { std::cout << std::quoted(arg) << ' '; }
};
```

C++17

```cpp
template<typename... Bases>
struct overloaded : Bases...
{
    using Bases::operator()...;
};

template<typename... Bases>
overloaded(Bases...) -> overloaded<Bases...>;

overloaded printer = {
    [](auto arg) { std::cout << arg << ' '; },
    [](double arg) { std::cout << std::fixed << arg << ' '; },
    [](const char* arg) { std::cout << std::quoted(arg) << ' '; }
};

int main()
{
    printer("Hello, World!");
}
```

C++17

```cpp
template<typename... Bases>
struct overloaded : Bases...
{
    using Bases::operator()...;
};

template<typename... Bases>
overloaded(Bases...) -> overloaded<Bases...>;

overloaded printer = {
    [](auto arg) { std::cout << arg << ' '; },
    [](double arg) { std::cout << std::fixed << arg << ' '; },
    [](const char* arg) { std::cout << std::quoted(arg) << ' '; }
};

int main()
{
    printer("Hello, World!");
}
```

C++20

```cpp
template<typename... Bases>
struct overloaded : Bases...
{
    using Bases::operator()...;
};





overloaded printer = {
    [](auto arg) { std::cout << arg << ' '; },
    [](double arg) { std::cout << std::fixed << arg << ' '; },
    [](const char* arg) { std::cout << std::quoted(arg) << ' '; }
};

int main()
{
    printer("Hello, World!");
}
```

```
namespace pmr {
    template <class T>
    using vector = std::vector<T, std::pmr::polymorphic_allocator<T>>;
}
```

C++17

```
std::pmr::vector<int> v{1, 2, 3};
```

```cpp
namespace pmr {
    template <class T>
    using vector = std::vector<T, std::pmr::polymorphic_allocator<T>>;
}
```

C++17

```cpp
std::pmr::vector<int> v{1, 2, 3};
```

C++20

```cpp
std::pmr::vector v{1, 2, 3};
```

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In C++20, in a constexpr function you can:

- have a try-block
- have an unevaluated asm block
- use a union
- call virtual functions
- dynamic_cast and typeid
- new and delete

Daveed Vandevoorde

“C++ Constants”

C++Now 2019 keynote

Louis Dionne

"Compile-time programming and reflection in C++20 and beyond”

CppCon 2018 talk

“running” code at compile time

```
int square(int i) {
    return i * i;
}
```

“running” code at compile time

```
constexpr int square(int i) {
    return i * i;
}

square(3);  // compile time
square(x);  // runtime
```

“running” code at compile time

```
consteval int square(int i) {
    return i * i;
}

square(3);  // compile time
square(x);  // Error - x is not a compile-time constant!
```

compile time or runtime?

```
int square(int i) {
    return __magic_fast_square(i);  // contains runtime magic
}

square(3);  // runtime, fast magic
square(x);  // runtime, fast magic
```

compile time or runtime?

```
constexpr int square(int i) {
    return i * i;
}

square(3);  // compile time
square(x);  // runtime, no fast magic :(
```

compile time or runtime?

```
constexpr int square(int i) {
    if (std::is_constant_evaluated()) {
        return i * i;
    }
    else {
        return __magic_fast_square(i);
    }
}

square(3);  // compile time
square(x);  // runtime, fast magic :)
```

compile time or runtime?

```
constexpr int square(int i) {
    if (std::is_constant_evaluated()) {
        return i * i;
    }
    else {
        return __magic_fast_square(i);
    }
}

square(3);  // compile time
square(x);  // runtime, fast magic :)
```

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```cpp
template <typename Container>
auto findFirstValid(const Container& c) -> Container::iterator
{
    return std::find_if(c.begin(), c.end(), [](auto elem){ return elem.is_valid(); });
}
```

```
template <typename Container>
auto findFirstValid(const Container& c) -> Container::const_iterator
{
    return std::find_if(c.begin(), c.end(), [](auto elem){ return elem.is_valid(); });
}


// Error: missing 'typename' prior to dependent type name ‘Container::const_iterator'
```

```
template <typename Container>
auto findFirstValid(const Container& c) -> Container::const_iterator
{
    return std::find_if(c.begin(), c.end(), [](auto elem){ return elem.is_valid(); });
}

// OK in C++20 :)
```

New attributes in C++20

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- [[likely]], [[unlikely]]
- [[no_unique_address]]
- [[nodiscard]] on constructors
- [[nodiscard(“can have a message”)]]

Using enum

```cpp
enum class rgba_color_channel {
    red,
    green,
    blue,
    alpha
};
```

Using enum

```cpp
enum class rgba_color_channel {
    red,
    green,
    blue,
    alpha
};

std::string_view to_string(rgba_color_channel channel) {
    switch (channel) {
        case rgba_color_channel::red:   return "red";
        case rgba_color_channel::green: return "green";
        case rgba_color_channel::blue:  return "blue";
        case rgba_color_channel::alpha: return "alpha";
    }
}
```

Using enum

```
enum class rgba_color_channel {
    red,
    green,
    blue,
    alpha
};

std::string_view to_string(rgba_color_channel channel) {
    switch (channel) {
        case rgba_color_channel::red:   return "red";
        case rgba_color_channel::green: return "green";
        case rgba_color_channel::blue:  return "blue";
        case rgba_color_channel::alpha: return "alpha";
    }
}
```

Using enum

```cpp
enum class rgba_color_channel {
    red,
    green,
    blue,
    alpha
};

std::string_view to_string(rgba_color_channel channel) {
    switch (channel) {
        using enum rgba_color_channel;

        case red:   return "red";
        case green: return "green";
        case blue:  return "blue";
        case alpha: return "alpha";
    }
}
```

Using enum

```
enum class Suit {
    diamonds,
    hearts,
    spades,
    clubs
};

class Card {
    using enum Suit;
    Suit suit = spades;
};
```

Built-in UTF-8 char type

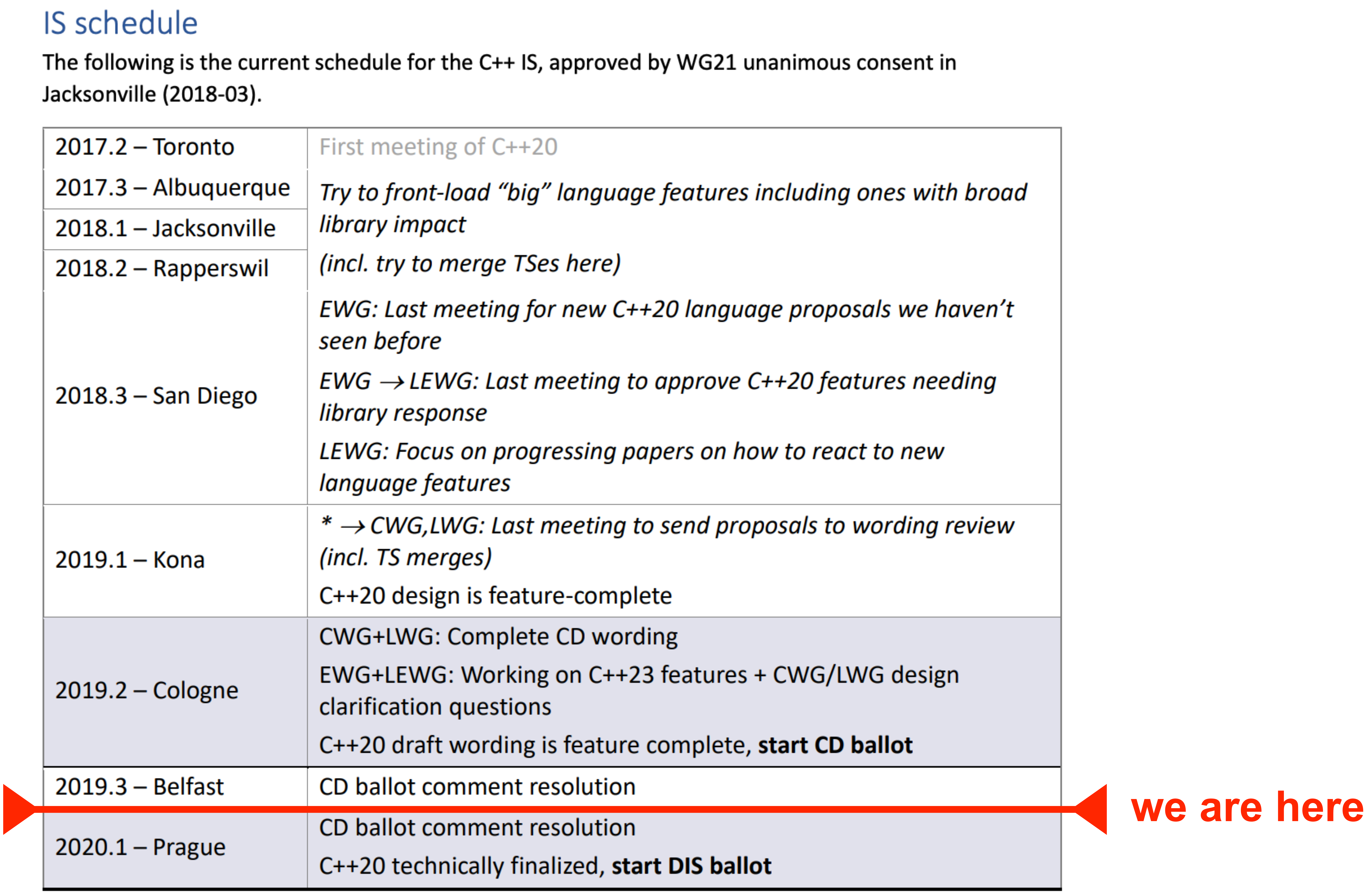
```
int main() {
    const char* str = u8"🌈❤️";  // C++17...
}
```

Built-in UTF-8 char type

```
int main() {
    const char* str = u8"🌈❤️";  // compile error in C++20!
}
```

Built-in UTF-8 char type

```
int main() {
    const char8_t* str = u8"🌈❤️";
}
```



IS schedule

The following is the current schedule for the C++ IS, approved by WG21 unanimous consent in Jacksonville (2018-03).

2017.2 – Toronto	First meeting of C++20
2017.3 – Albuquerque	*Try to front-load "big" language features including ones with broad library impact* *(incl. try to merge TSes here)*
2018.1 – Jacksonville	
2018.2 – Rapperswil	
2018.3 – San Diego	*EWG: Last meeting for new C++20 language proposals we haven't seen before* *EWG → LEWG: Last meeting to approve C++20 features needing library response* *LEWG: Focus on progressing papers on how to react to new language features*
2019.1 – Kona	** → CWG,LWG: Last meeting to send proposals to wording review (incl. TS merges)* C++20 design is feature-complete
2019.2 – Cologne	CWG+LWG: Complete CD wording EWG+LEWG: Working on C++23 features + CWG/LWG design clarification questions C++20 draft wording is feature complete, **start CD ballot**
2019.3 – Belfast	CD ballot comment resolution
2020.1 – Prague	CD ballot comment resolution C++20 technically finalized, **start DIS ballot**

we are here

C++20: The small things

Version 1.3

Timur Doumler

@timur_audio

MeetingC++
14 November 2019