Design Rationale for the <chrono> Library

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Ripple

Meeting C++ 2019

Structure of <chrono>

- Durations:

- Introduced in C++11

- These six durations represent the convenient high-level access.

- lower-level access is available to clients for creating any duration unit they need.

hours

minutes

seconds

milliseconds

microseconds

nanoseconds

- Durations are the heart of the <chrono> library.

Structure of <chrono>

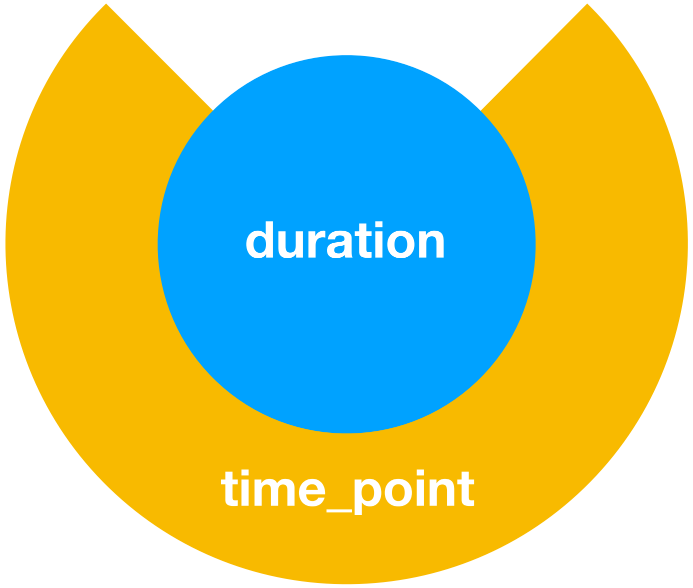
- Introduced in C++11

duration

Structure of <chrono>

- Time points:

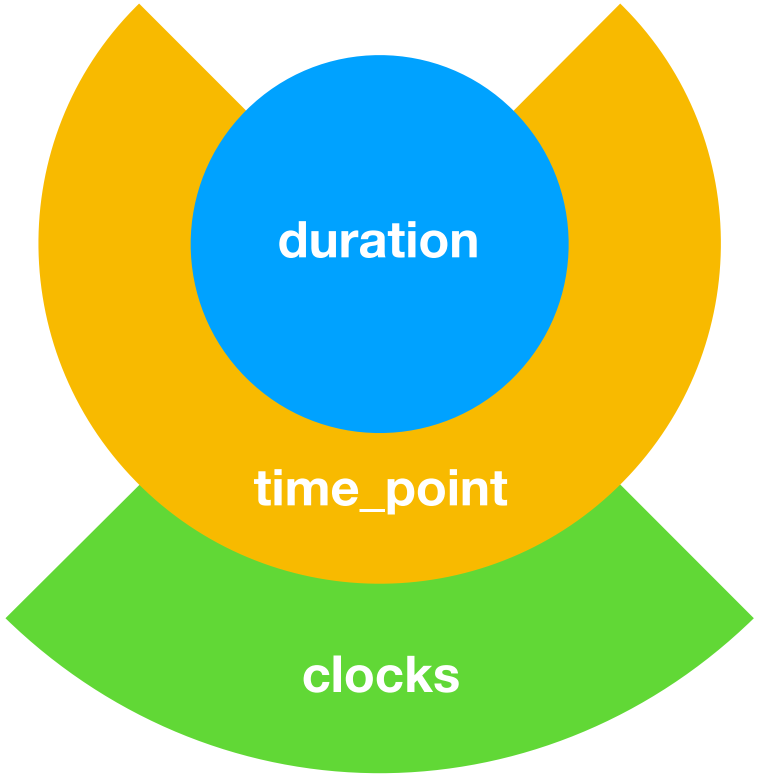
- Introduced in C++11



Structure of <chrono>

- Clocks:

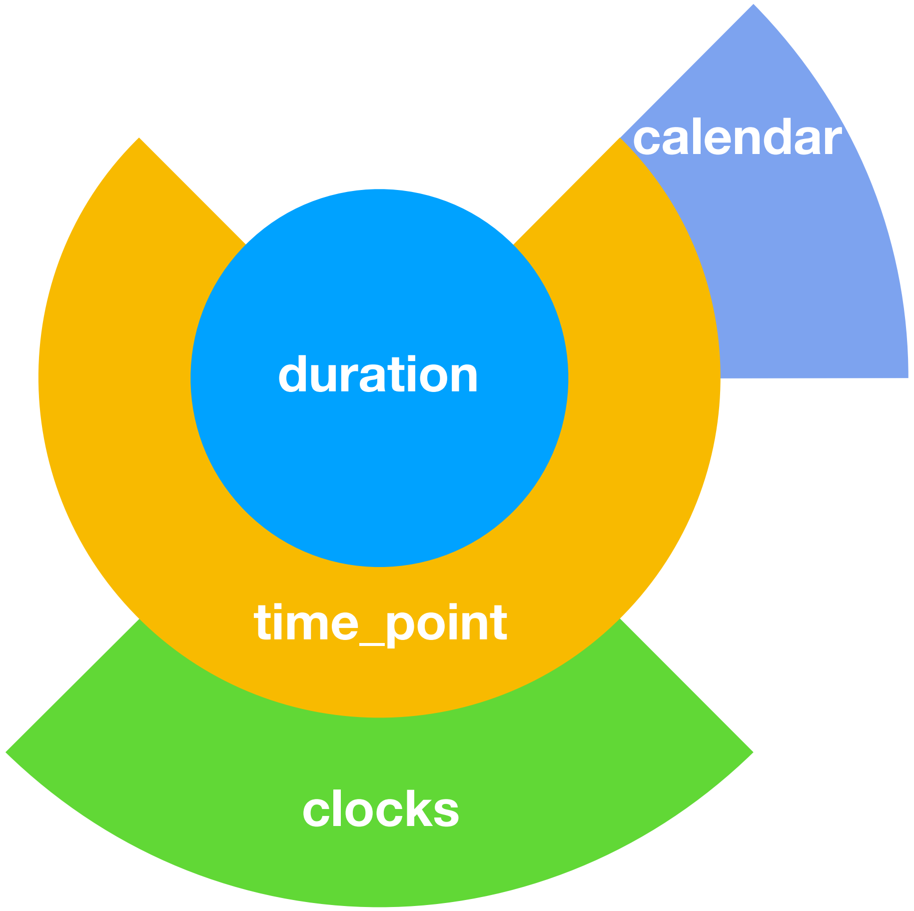
- Introduced in C++11



Evolution of <chrono>

Calendrical types:

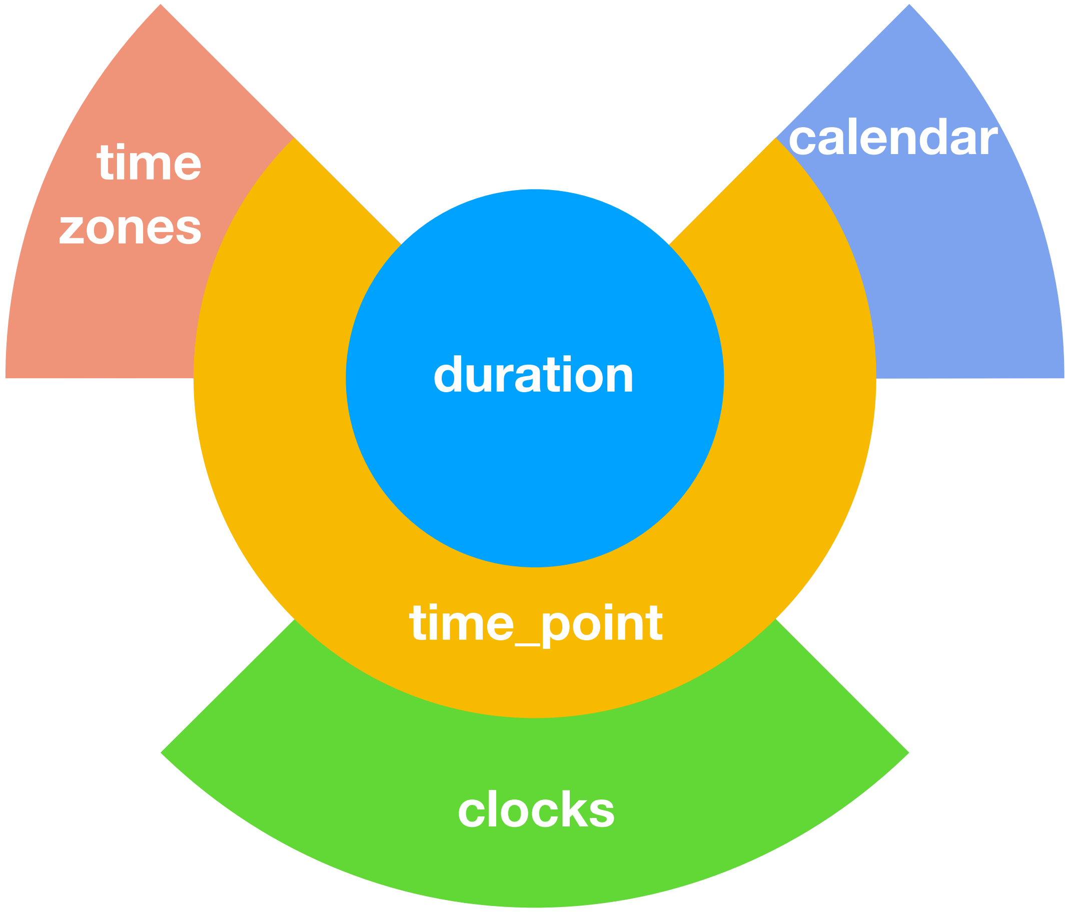
- Coming in C++20



Evolution of <chrono>

Time zone management:

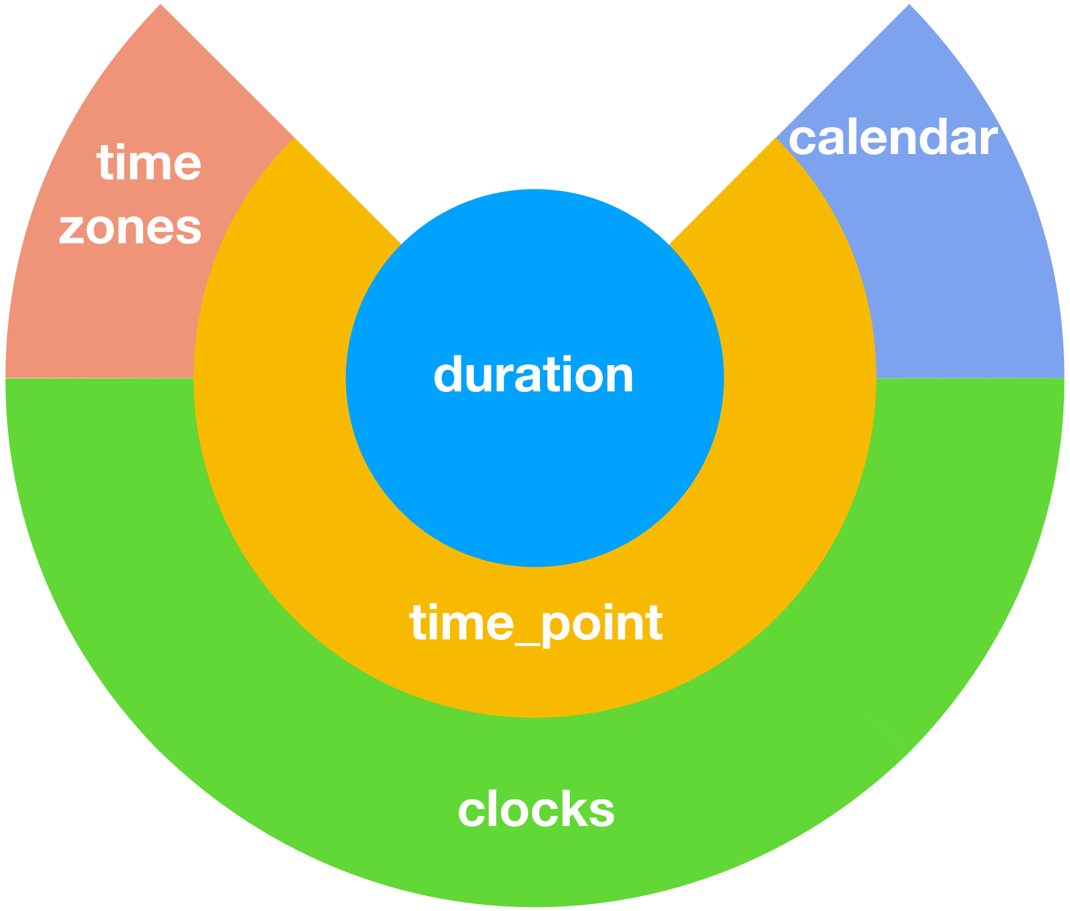
- Coming in C++20



Evolution of <chrono>

And more clocks:

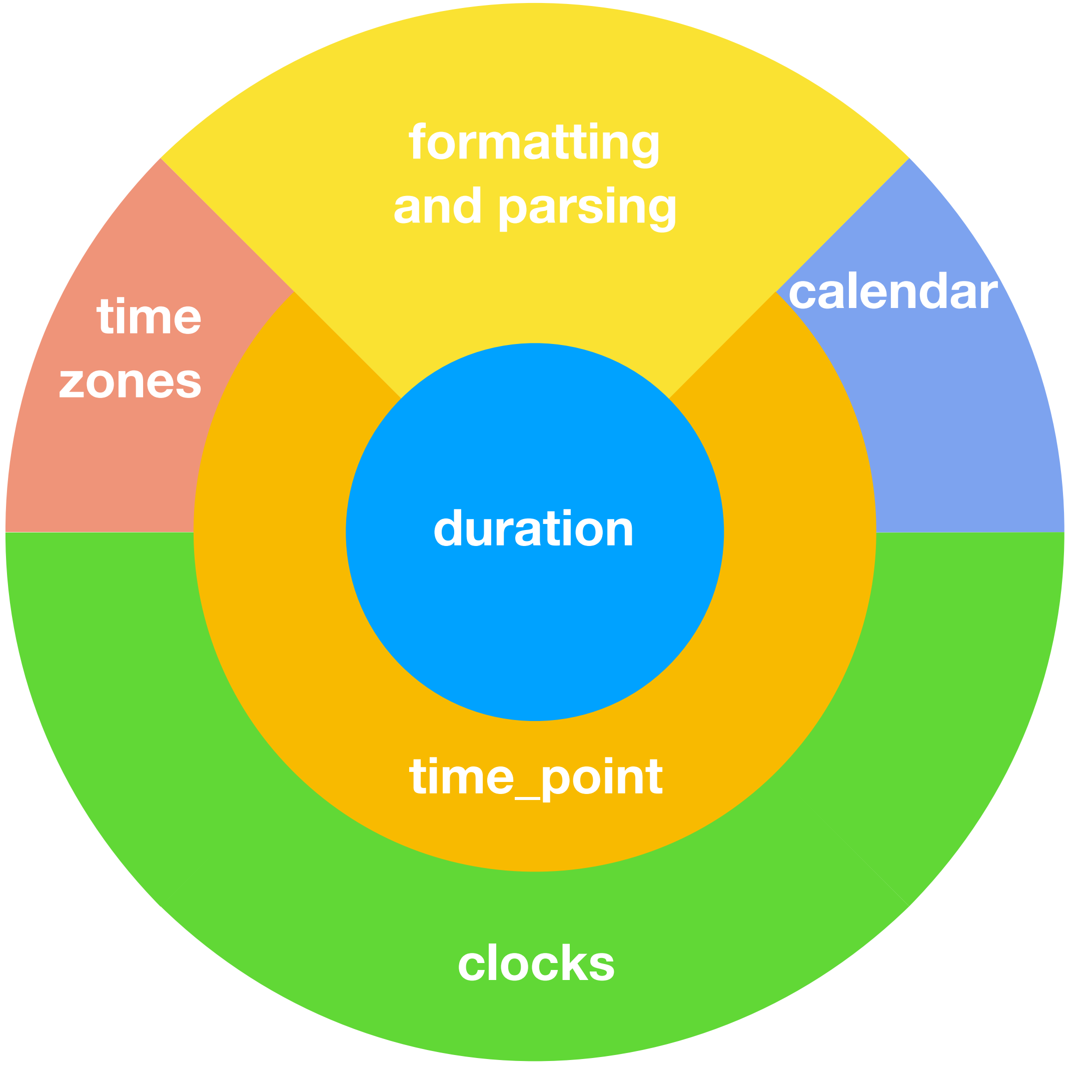
- Coming in C++20



Evolution of <chrono>

Formatting and parsing:

- Coming in C++20



C++20 provides a *complete* time handling library.

chrono in C++20

- **Everything** talked about today, whether it is old types from C++11 (e.g. durations and time_points) or new types in C++20, has a streaming operator in C++20:

```
cout << system_clock::now() << '\n';
```

- C++20 <chrono> becomes *much* easier to work with because you can easily print values out, even without knowing their type.

```
auto t0 = steady_clock::now();
...
auto t1 = steady_clock::now();
cout << "That took " << t1-t0 << '\n';
```

```
// That took 657ns
```

duration

```
template<class Rep, class Period = ratio<1>>
   class duration;
```

- `duration` represents a duration of time, and can come in any unit.
- `durations` are represented by an arithmetic type, or a class type emulating an arithmetic type.
  - `int`, `long`, `double`, `safe<int>`, etc.
- `duration::period` is a compile-time fraction representing the time in seconds between each integral value stored in the duration.
- <chrono> defines several convenience type aliases for common units.

duration

```
template<class Rep, class Period = ratio<1>>
   class duration;
```

- <chrono> defines several convenience type aliases for common units.

New in C++20

```
nanoseconds
microseconds
milliseconds
seconds
minutes
hours
```

```
days
weeks
months
years
```

duration

```
template<class Rep, class Period = ratio<1>>
   class duration;
```

- Clients can define any custom unit they want.

```
using dsec = duration<double>;

using frame_rate = duration<int, ratio<1, 60>>;

using safe_ns = duration<safe_int<int64_t>, nano>;
```

duration

```
template<class Rep, class Period = ratio<1>>
   class duration;
```

- Durations implicitly convert from coarse to fine:

```
auto limit = 2h;
milliseconds x = limit;  // 7'200'000ms
```

duration

```
template<class Rep, class Period = ratio<1>>
   class duration;
```

- Durations have a named conversion from fine to coarse:

```
auto limit = 2h;
milliseconds x = limit;  // 7'200'000ms
auto y = duration_cast<hours>(x);  // 2h
```

duration

```
template<class Rep, class Period = ratio<1>>
   class duration;
```

- If the destination is floating-point-based, converts implicitly

```
auto limit = 2h;
milliseconds x = limit;  // 7'200'000ms
auto y = duration_cast<hours>(x);  // 2h
duration<double> z = x;  // 7'200.0s
```

- Implicit truncation error is a compile-time error.
- Round-off error is not a compile-time error.

time_point

```
template<class Clock, class Duration = typename Clock::duration>
   class time_point;
```

- `time_point` represents a point in time.
- time_point is a wrapper around a duration.
  - Same value, same representation, just a different meaning.
- time_point offers only a subset of arithmetic algebra so as to catch logic errors at compile-time.

time_point

```
template<class Clock, class Duration = typename Clock::duration>
   class time_point;
```

- time_point offers only a subset of arithmetic algebra so as to catch logic errors at compile-time.

```
auto tp1 = system_clock::now();  // tp1 is a time_point
auto tp2 = system_clock::now();  // tp2 is a time_point
auto diff = tp2 - tp1;           // diff is a duration
auto sum = tp2 + tp1;            // compile-time error
```

time_point

```
template<class Clock, class Duration = typename Clock::duration>
   class time_point;
```

- time_point is templated on Clock to catch the error of mixing time_points from different clocks.

```
auto tp1 = system_clock::now();  // tp1 is a time_point
auto tp2 = steady_clock::now();  // tp2 is a time_point
auto diff = tp2 - tp1;           // compile-time error
```

What is the difference between a time point and a date?

- Example time points:
  - 2019-11-14 10:30:15
  - 2019-11-14 10:30:15.123
  - 2019-11-14 10:30:15.123456
  - 2019-11-14 10:30:15.123456789

Time points can have arbitrarily fine precision.

What is the difference between a time point and a date?

- Example time points:
  - 2019-11-14 10:30:15
  - 2019-11-14 10:30:15.123
  - 2019-11-14 10:30:15.123456
  - 2019-11-14 10:30:15.123456789
  - 2019-11-14 10:30
  - 2019-11-14 10

Time points can have arbitrarily coarse precision.

What is the difference between a time point and a date?

- Example time points:
  - 2019-11-14 10:30:15
  - 2019-11-14 10:30:15.123
  - 2019-11-14 10:30:15.123456
  - 2019-11-14 10:30:15.123456789
  - 2019-11-14 10:30
  - 2019-11-14 10
  - 2019-11-14

When the time point has a precision of a day, we call it a date.

What is the difference between a time point and a date?

- Example time points:

Each precision has a type in the chrono system.

2019-11-14 10:30:15	`time_point<system_clock, seconds>`
2019-11-14 10:30:15.123	`time_point<system_clock, milliseconds>`
2019-11-14 10:30:15.123456	`time_point<system_clock, microseconds>`
2019-11-14 10:30:15.123456789	`time_point<system_clock, nanoseconds>`
2019-11-14 10:30	`time_point<system_clock, minutes>`
2019-11-14 10	`time_point<system_clock, hours>`
2019-11-14	`time_point<system_clock, days>`

What is the difference between a time point and a date?

`sys_time<Duration>`
is a type alias for
`time_point<system_clock, Duration>`

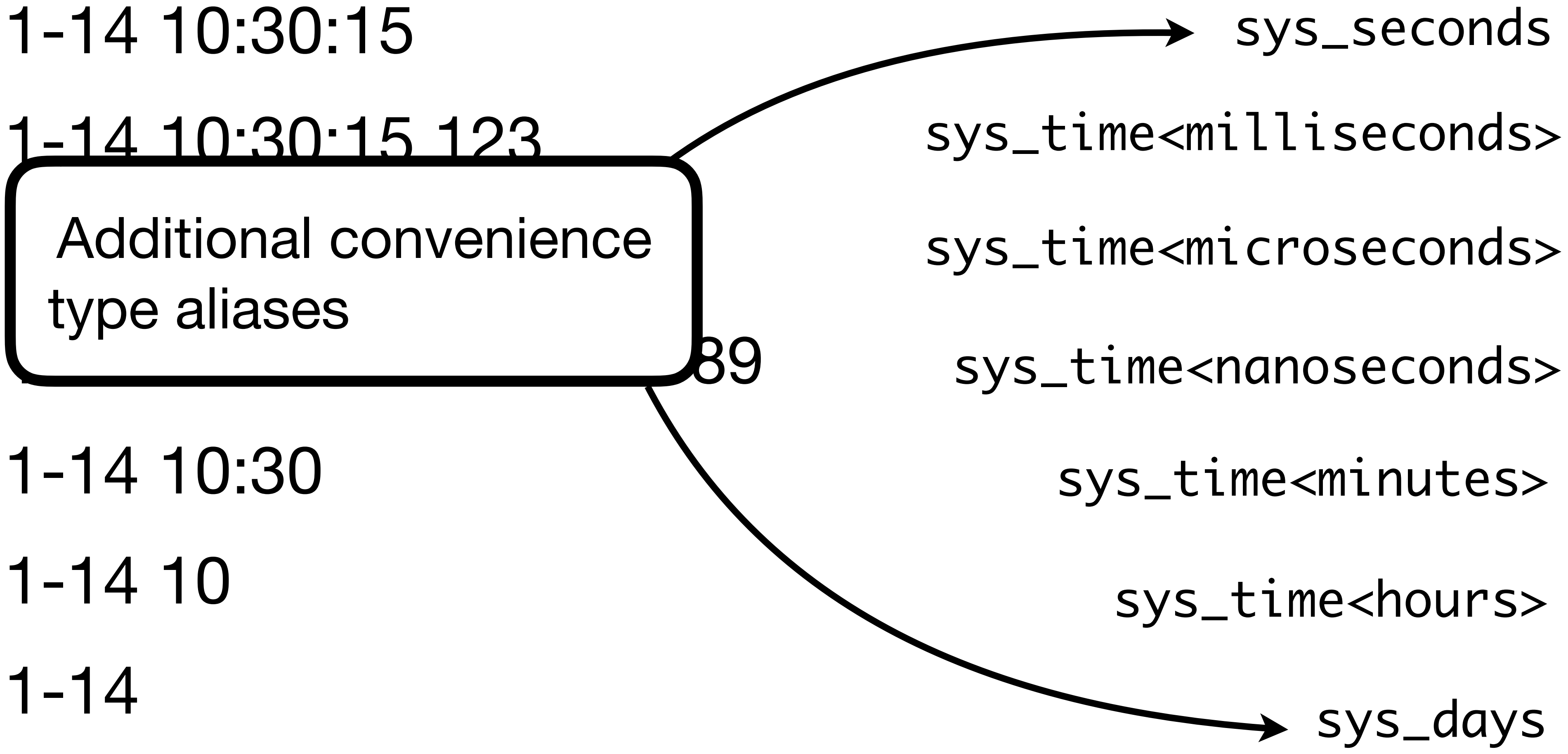
- Example time points:

2019-11-14 10:30:15	`sys_time<seconds>`
2019-11-14 10:30:15.123	`sys_time<milliseconds>`
2019-11-14 10:30:15.123456	`sys_time<microseconds>`
2019-11-14 10:30:15.123456789	`sys_time<nanoseconds>`
2019-11-14 10:30	`sys_time<minutes>`
2019-11-14 10	`sys_time<hours>`
2019-11-14	`sys_time<days>`

What is the difference between a time point and a date?

`sys_time<Duration>`
is a type alias for
`time_point<system_clock, Duration>`

- Example time points:
  - 2019-11-14 10:30:15
  - 2019-11-14 10:30:15 123
  - 2019-1
  - 2019-1 89
  - 2019-11-14 10:30
  - 2019-11-14 10
  - 2019-11-14



Additional convenience type aliases

`sys_seconds`

`sys_time<milliseconds>`

`sys_time<microseconds>`

`sys_time<nanoseconds>`

`sys_time<minutes>`

`sys_time<hours>`

`sys_days`

What is a calendar?

- A calendar is a collection of dates, where each date has a unique name.

Civil calendar

30.12.1969
31.12.1969
01.01.1970
02.01.1970
03.01.1970

What is a calendar?

- A calendar is a collection of dates, where each date has a unique name.

Civil calendar	Julian calendar
30.12.1969	17.12.1969
31.12.1969	18.12.1969
01.01.1970	19.12.1969
02.01.1970	20.12.1969
03.01.1970	21.12.1969

- Different calendars can refer to the same physical date, but have different names for that date.

What is a calendar?

- A calendar is a collection of dates, where each date has a unique name.

Civil calendar	sys_days
30.12.1969	-2
31.12.1969	-1
01.01.1970	0
02.01.1970	1
03.01.1970	2

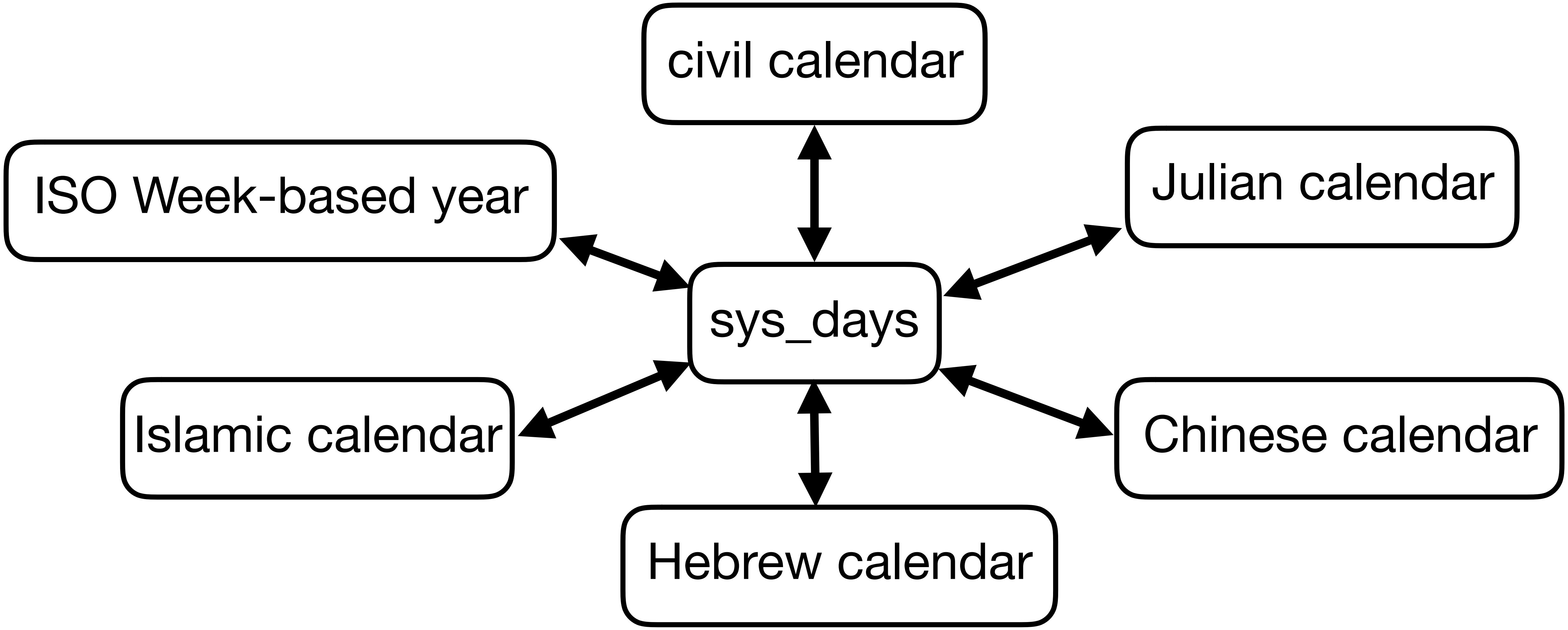
- sys_days is a calendar too!

Calendar Interoperability

sys_days

- sys_days is the canonical calendar in <chrono>.

Calendar Interoperability



civil calendar

ISO Week-based year

Julian calendar

sys_days

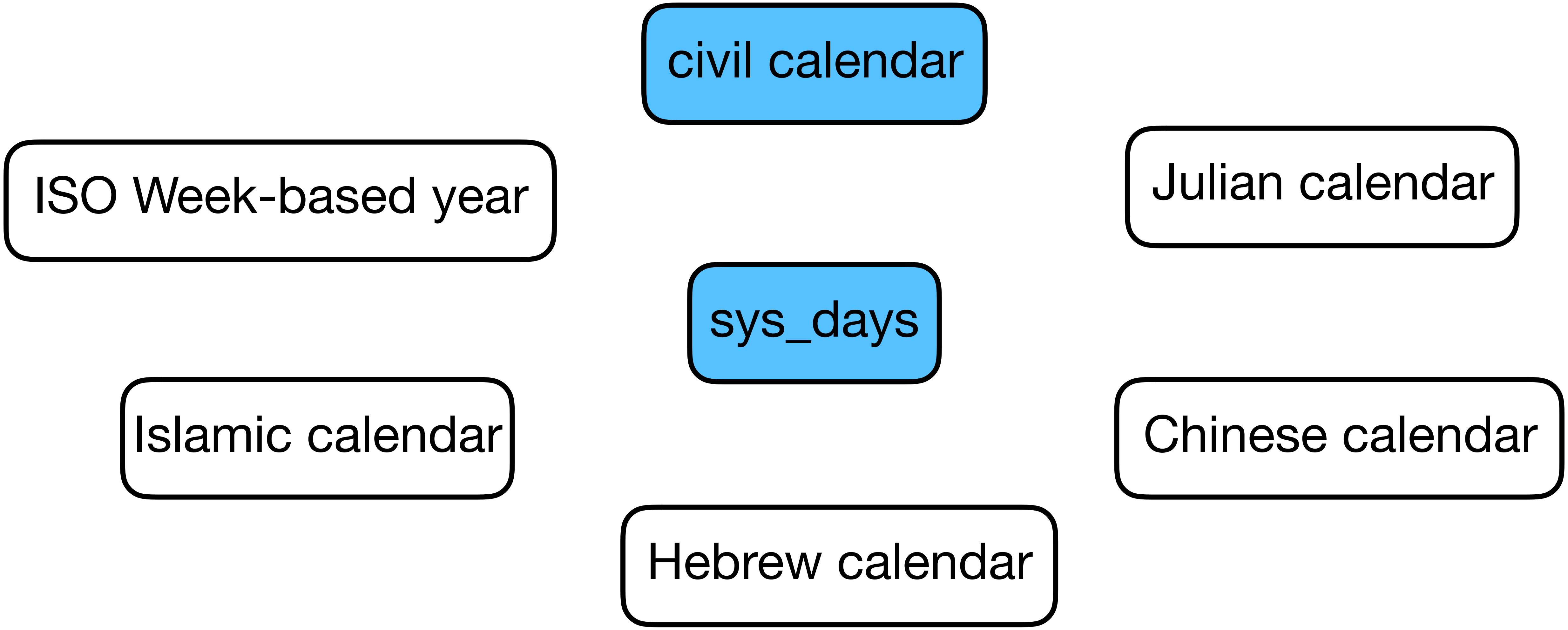
Islamic calendar

Chinese calendar

Hebrew calendar

- sys_days is the canonical calendar in <chrono>.
- As long as each calendar can convert to and from sys_days, then each calendar can convert to any other calendar.

Calendar Interoperability



civil calendar

ISO Week-based year

Julian calendar

sys_days

Islamic calendar

Chinese calendar

Hebrew calendar

- Only these two calendars are in C++20 <chrono>.
- Clients can write their own calendars.
    - I've written several of them as proof of concept.

The civil calendar

```
class year_month_day;
```

data structure: `{year, month, day}`

- `year_month_day` implicitly converts to and from `sys_days`, with no loss of information (`constexpr` and `noexcept`).
- Constructible from a `year`, `month` and `day`.
- Has `year`, `month` and `day` getters.
- Equality and less-than comparable.
- Does year and month-oriented arithmetic.
- Does *not* do day-oriented arithmetic. `sys_days` does day-oriented arithmetic *very* efficiently.

The civil calendar

```
class year;
```

data structure: `{short}`

- `year` represents the "name" of a year in the civil calendar. It does not represent a number of `years` (a duration).
    - One can subtract two `year` instances and get a `years` duration type.
- `year` **explicitly** converts to and from `int`.
- Equality and less-than comparable.
- Does year-oriented arithmetic.
- Has user-defined literal y, e.g. `2019`y.

The civil calendar

`class month;`

data structure: `{unsigned char}`

- `month` represents a month of a `year`. It does not represent a number of `months` (a duration).
  - One can subtract two `month` instances and get a `months` duration type.
- `month` **explicitly** converts to and from `unsigned`.
- Equality and less-than comparable.
- Does month-oriented arithmetic (modulo 12).
- Has `inline constexpr` constants, e.g. `January, February, March, ...`

The civil calendar

```
class day;
```

data structure: `{unsigned char}`

- `day` represents a day of a `month`. It does not represent a number of `days` (a duration).
  - One can subtract two `day` instances and get a `days` duration type.
- `day` **explicitly** converts to and from `unsigned`.
- Equality and less-than comparable.
- Does day-oriented arithmetic.
- Has user-defined literal `d`, e.g. `14d`.

The civil calendar

```
class year_month_day;
```

data structure: `{year, month, day}`

- Typically sizeof is 4 bytes.

The civil calendar

```
class year_month_day;
```

data structure: `{year, month, day}`

- Typically sizeof is 4 bytes.
- Constructible with conventional syntax operators in 3 different orders:

```
auto ymd = 2019y/November/14d;

auto ymd = 14d/November/2019y;

auto ymd = November/14d/2019y;
```

The civil calendar

```
class year_month_day;
```

data structure: `{year, month, day}`

- Typically sizeof is 4 bytes.
- Constructible with conventional syntax operators in 3 different orders:
- Only the first field must be typed, the trailing fields can be integral.

```
auto ymd = 2019y/11/14;

auto ymd = 14d/11/2019;

auto ymd = November/14/2019;
```

The civil calendar

```
class year_month_day;
```

data structure: `{year, month, day}`

- Or, if you prefer:

```
year_month_day ymd{year{2019}, month{11}, day{14}};
```

The civil calendar

`class year_month_day;`

data structure: `{year, month, day}`

- Construction was designed to be type-safe and readable, but not overly verbose.
- Try to eliminate errors such as
  - `year_month_day{10, 11, 12}`.

The civil calendar

```
class year_month_day;
```

data structure: `{year, month, day}`

- Invalid dates are allowed, but are easily detectable.

```
auto ymd = November/31/2019;
assert(ymd.ok() == false);
```

- Rationale: Invalid dates are not necessarily errors (examples to follow later). And if they are errors, **you** get to decide if they are fatal, exceptional, or handled with an error code.

The civil calendar

```
class year_month_day_last;
```

data structure: `{year, month}`

- Represents the last day of the {year, month} pair.
- Constructible from a `year` and `month`.
- Implicitly convertible *to* `sys_days` (it's a partial calendar).
- Has `year` and `month` and `day` getters.
- Equality and less-than comparable.
- Does year and month-oriented arithmetic.

The civil calendar

```
class year_month_day_last;
```

data structure: `{year, month}`

- Constructible with conventional syntax operators by replacing the day-specifier with `last`.

```
auto ymd = last/November/2019;
```

- Implicitly convertible to `year_month_day`.

```
year_month_day ymd = November/last/2019;
```

The civil calendar

More about year and month arithmetic

- Consider:

```
auto ymd = 31d/October/2019;
ymd += months{1};
```

- ymd has the value `2019y/November/31d`

The civil calendar

More about year and month arithmetic

- Consider:

```
auto ymd = 31d/October/2019;
ymd += months{1};
```

- ymd has the value `2019y/November/31d`

- To snap to the end of the month:

```
if (!ymd.ok())
    ymd = ymd.year()/ymd.month()/last;
```

The civil calendar

More about year and month arithmetic

- Consider:

```
auto ymd = 31d/October/2019;
ymd += months{1};
```

- ymd has the value `2019y/November/31d`

- To snap to the end of the month:

```
if (!ymd.ok())
    ymd = ymd.year()/ymd.month()/last;
```

- To overflow into the next month:

```
if (!ymd.ok())
    ymd = sys_days{ymd};
```

The civil calendar

More about year and month arithmetic

- To snap to the end of the month:

```
if (!ymd.ok())
    ymd = ymd.year()/ymd.month()/last;
```

- To overflow into the next month:

```
if (!ymd.ok())
    ymd = sys_days{ymd};
```

- In either case, the invalid date 2019-11-31 is not a fatal nor exceptional error. It is just an intermediate result.
  - **You** get to decide how to handle it.

The civil calendar

```
class year_month_weekday;
```

data structure: `{year, month, weekday_indexed}`

```
auto date = Thursday[2]/November/2019;
```

- Represents dates of the form the 2nd Thursday of November 2019.
- Constructible with conventional syntax
  - Anywhere one can put a day-specifier, one can use a `weekday_indexed` instead.
- `year_month_weekday` implicitly converts to and from `sys_days`, with no loss of information (`constexpr` and `noexcept`).
- This is a *second* complete civil calendar!

The civil calendar

`class year_month_weekday;`

data structure: `{year, month, weekday_indexed}`

```
auto date = Thursday[2]/November/2019;
```

- Has `year`, `month`, `weekday`, and `index` getters.
- Equality comparable (not less-than).
- Does year and month-oriented arithmetic.
- Will explicitly convert to and from `year_month_day` by bouncing off of `sys_days` (just like a user-written calendar).

The civil calendar

`class weekday;`

data structure: `{unsigned char}`

- `weekday` **explicitly** converts to and from `unsigned`.
  - Constructor accepts both C's `tm` encoding and ISO encoding.
- Explicitly constructible *from* `sys_days` (a partial calendar).
- Equality comparable (not less-than).
- Does day-oriented arithmetic (modulo 7).
  - Implies there is no officially supported "first day of the week."
- Has `inline constexpr` constants, e.g. `Monday`, `Tuesday`, `Wednesday`, ...

The civil calendar

```
class weekday_indexed;
```

data structure: `{weekday, integral index}  // allowed to be 1 byte`

- Represents the concept: n^{th} weekday of an unspecified month.
- `weekday_indexed` constructs from a `weekday` and an `unsigned`.
- Constructible with conventional syntax:

```
auto wdi = Thursday[2];
```

The civil calendar

```
class weekday_last;
```

data structure: `{weekday}`

- Represents the concept: last weekday of an unspecified month.
- `weekday_last` explicitly constructs from a `weekday`.
- Constructible with conventional syntax:

```
auto wdi = Thursday[last];
```

The civil calendar

More about year and month arithmetic

- Consider:

```
auto date = Friday[5]/November/2019;
date += years{1};
```

- `date` has the value `Friday[5]/November/2020.` But `November/2020` only has 4 Fridays.

The civil calendar

More about year and month arithmetic

- Consider:

```
auto date = Friday[5]/November/2019;
date += years{1};
```

- `date` has the value `Friday[5]/November/2020.` But `November/2020` only has 4 Fridays.
- To snap to the end of the month (4th Friday of `November/2020`):

```
if (!date.ok())
    date = sys_days{date.year()/date.month()/date.weekday()[last]};
```

The civil calendar

More about year and month arithmetic

- Consider:

```
auto date = Friday[5]/November/2019;
date += years{1};
```

- `date` has the value `Friday[5]/November/2020`. But `November/2020` only has 4 Fridays.
- To snap to the end of the month (4th Friday of `November/2020`):

```
if (!date.ok())
    date = sys_days{date.year()/date.month()/date.weekday()[last]};
```

- To overflow into the next month (1st Friday of December/2020):

```
if (!date.ok())
    date = sys_days{date};
```

Time Zones

- `system_clock` (and `sys_time<Duration>`) are Unix Time.
- Unix Time measures time since (and prior) 1970-01-01 00:00:00 UTC excluding leap seconds.
- Yes, C++20 can handle leap seconds but `sys_time` ignores them (we'll get there ...).

Time Zones

- `system_clock` (and `sys_time<Duration>`) are Unix Time.
- Unix Time measures time since (and prior) 1970-01-01 00:00:00 UTC excluding leap seconds.
- Yes, C++20 can handle leap seconds but `sys_time` ignores them (we'll get there ...).
- C++20 adds a `time_zone` class which is used to transform `sys_time<Duration>` into "local time".
- C only has the concept of UTC and "local time". C++20 adds to these two concepts the ability to compute with any time zone in the IANA time zone database.
  - This means time zone names are portable.

Time Zones

- Examples:

The current UTC time:

```
auto tp = system_clock::now();
```

```
2019-11-14 10:13:40.785346
```

Time Zones

- Examples:

The current UTC time:

```
auto tp = system_clock::now();
```

```
2019-11-14 10:13:40.785346
```

The current local time:

```
zoned_time tp{current_zone(), system_clock::now()};
```

```
2019-11-14 11:13:40.785346 CET
```

Time Zones

- Examples:

The current UTC time:

```
auto tp = system_clock::now();
```

```
2019-11-14 10:13:40.785346
```

The current local time:

```
zoned_time tp{current_zone(), system_clock::now()};
```

```
2019-11-14 11:13:40.785346 CET
```

The current time in Berlin:

```
zoned_time tp{"Europe/Berlin", system_clock::now()};
```

```
2019-11-14 11:13:40.785346 CET
```

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

- `zoned_time` is a convenience wrapper of a pointer to a time zone, and a `sys_time` `time_point`.
- One can think of it as a triple of `{time_zone*, local_time<Duration>, sys_time<Duration>}`, but the local time is computed upon demand.
- One can create custom time zones to handle things outside the IANA time zone database (e.g. POSIX time zone strings).

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

- `zoned_time` is typically constructed with two arguments.
- The first argument represents a `time_zone`.
  - Can be either a `time_zone const*`, or a `string_view`.
- The second argument represents a `time_point`.
  - Can be a `sys_time`, `local_time`, or another `zoned_time`.

```
zoned_time zt{A time zone, A time point};
```

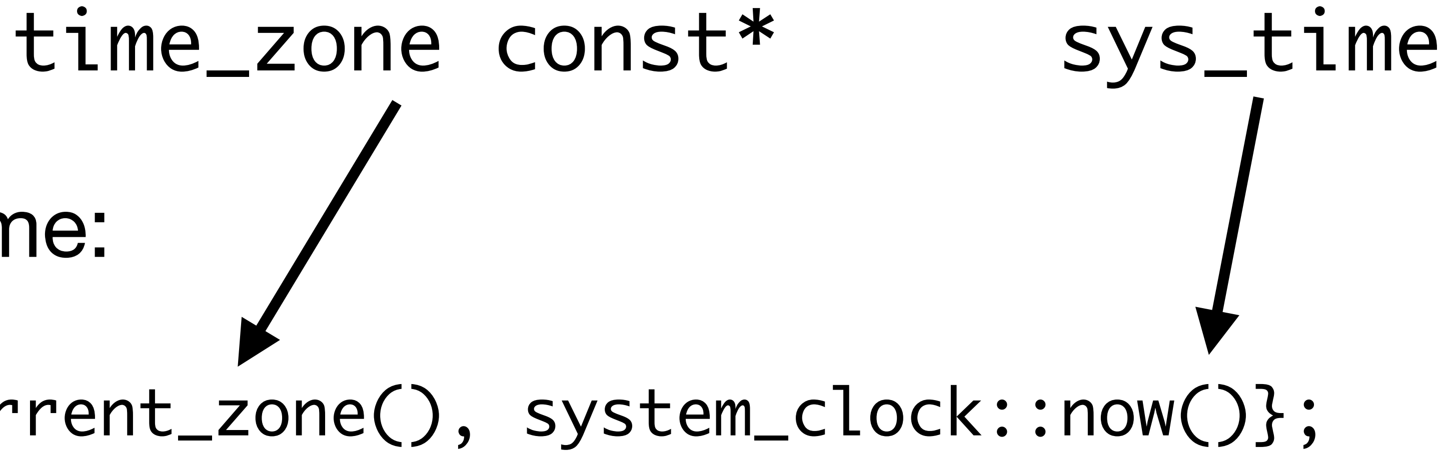
Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time zt{A time zone, A time point};
```

- `Examples:`



`time_zone const*`   `sys_time`

The current local time:

```
zoned_time tp{current_zone(), system_clock::now()};
```

```
2019-11-14 11:13:40.785346 CET
```

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time zt{A time zone, A time point};
```

- Examples:

`string_view`

`sys_time`

The current Berlin time:

```
zoned_time tp{"Europe/Berlin", system_clock::now()};
```

```
2019-11-14 11:13:40.785346 CET
```

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time zt{A time zone, A time point};
```

- `Examples:`

`string_view` `local_time`

Midnight Berlin time:

```
zoned_time tp{"Europe/Berlin", local_days{2019y/11/14}};
```

```
2019-11-14 00:00:00 CET
```

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time zt{A time zone, A time point};
```

- `Examples:`

`string_view`

`sys_time`

1:00 Berlin time:

```
zoned_time tp{"Europe/Berlin", sys_days{2019y/11/14}};
2019-11-14 01:00:00 CET
```

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time zt{A time zone, A time point};
```

- Examples:

1:00 Berlin time:

Specify local time of day

```
zoned_time tp{"Europe/Berlin", local_days{2019y/11/14} + 1h};
```

```
2019-11-14 01:00:00 CET
```

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time zt{A time zone, A time point};
```

- tp and tp2 represent the same UTC instant, but in different time zones

1:00 Berlin time:

```
zoned_time tp{"Europe/Berlin", local_days{2019y/11/14} + 1h};
               2019-11-14 01:00:00 CET

zoned_time tp2{"America/New_York", tp};
               2019-11-13 19:00:00 EST
```

zoned_time

Time Zones

`local_time<Duration>`
is a type alias for
`time_point<local_t, Duration>`

- `local_t` is "not really a clock."
  - It has no now() function.
- `local_time` is a `time_point` with respect to a not-yet-specified `time_zone`.
  - It can be paired with a `time_zone` and only then will it refer to an instant in time (e.g. in a `zoned_time` constructor).
- `local_days` is just a type alias for `local_time<days>`.
- Calendars convert back and forth to `local_days` with the exact same formulas that they use for `sys_days`.

Time Zones

`local_time<Duration>`
is a type alias for
`time_point<local_t, Duration>`

- Calendars convert back and forth to `local_days` with the exact same formulas that they use for `sys_days`.

`sys_days{2019y/11/14}`	A UTC `time_point`
`local_days{2019y/11/14}`	A somewhat nebulous `time_point`, until you pair it with a `time_zone`.

But both contain the value `18214 days`.

Time Zones

```
template<class Duration, class TimeZonePtr = const time_zone*>
class zoned_time;
```

data structure: `{TimeZonePtr, sys_time<Duration>}`

```
zoned_time tp{"Europe/Berlin", local_days{2019y/11/14} + 1h};

        tp.get_sys_time();          2019-11-14 00:00:00

        tp.get_local_time();        2019-11-14 01:00:00
```

- `sys_time` and `local_time` are distinct families of `time_points` so that the compiler will catch accidentally mixing them.
- They both have distinct semantics.
- They are both useful.
- They are both available.

Time Zones

Example: Directions Group meeting times

```
for (auto d = January/9/2019; d.year() < 2020y;
     d = sys_days{d} + weeks{2})
{
    zoned_time london{"Europe/London", local_days{d} + 18h};
    cout << london << '\n';
    cout << zoned_time{"America/New_York", london} << "\n\n";
}
```

Time Zones

Example: Directions Group meeting times

```
for (auto d = January/9/2019; d.year() < 2020y;
     d = sys_days{d} + weeks{2})
{
    zoned_time london{"Europe/London", local_days{d} + 18h};
    cout << london << '\n';
    cout << zoned_time{"America/New_York", london} << "\n\n";
}
```

```
2019-01-09 18:00:00 GMT
2019-01-09 13:00:00 EST

2019-01-23 18:00:00 GMT
2019-01-23 13:00:00 EST

...
```

Time Zones

Example: Directions Group meeting times

```
for (auto d = January/9/2019; d.year() < 2020y;
     d = sys_days{d} + weeks{2})
{
    zoned_time london{"Europe/London", local_days{d} + 18h};
    cout << london << '\n';
    cout << zoned_time{"America/New_York", london} << "\n\n";
}
```

```
2019-03-20 18:00:00 GMT
2019-03-20 14:00:00 EDT

2019-04-03 18:00:00 BST
2019-04-03 13:00:00 EDT

...
```

Time Zones

Example: Directions Group meeting times

```
for (auto d = January/9/2019; d.year() < 2020y;
     d = sys_days{d} + weeks{2})
{
    zoned_time london{"Europe/London", local_days{d} + 18h};
    cout << london << '\n';
    cout << zoned_time{"America/New_York", london} << "\n\n";
}
```

```
2019-10-30 18:00:00 GMT
2019-10-30 14:00:00 EDT

...

2019-12-25 18:00:00 GMT
2019-12-25 13:00:00 EST
```

Formatting

- Even though everything has a streaming operator, it may not stream with the format you desire.
- C++20 <chrono> fully integrates into C++20 `std::format`.
    - With all of the flag functionality of `std::strftime`/ `std::put_time`.
    - And a little more.

Formatting

- Given:

```
auto tp = system_clock::now();
auto tz = locale_zone("Europe/Berlin");
```

- Examples:

```
cout << zoned_time{tz, tp} << '\n';
```

```
2019-11-14 11:13:40.785346 CET
```

The default streaming format

Formatting

- Given:

```
auto tp = system_clock::now();
auto tz = locale_zone("Europe/Berlin");
```

- Examples:

```
cout << format("{:%F %T %Z}\n", zoned_time{tz, tp});
```

```
2019-11-14 11:13:40.785346 CET
```

No change.
The default explicitly specified.

Formatting

- Given:

```
auto tp = system_clock::now();
auto tz = locale_zone("Europe/Berlin");
```

- Examples:

```
cout << format("{:%d.%m.%Y %T%z}\n",
               zoned_time{tz, tp});
```

```
14.11.2019 11:13:40.785346+0100
```

d.m.y ordering.
UTC offset instead of time zone abbreviation.

Formatting

- Given:

```
auto tp = system_clock::now();
auto tz = locale_zone("Europe/Berlin");
```

- Examples:

```
cout << format(locale{"de_DE"}, "{:%d.%m.%Y %T%z}\n",
                zoned_time{tz, tp});
```

```
14.11.2019 11:13:40,785346+0100
```

Decimal point specified by explicit locale.
Your OS may not support this locale.

Formatting

- Given:

```
auto tp = system_clock::now();
auto tz = locale_zone("Europe/Berlin");
```

- Examples:

```
cout << format("{:%d.%m.%Y %T}\n",
           zoned_time{tz, floor<milliseconds>(tp)});

           14.11.2019 11:13:40.785
```

Precision governed by input time point precision.
Dropped UTC offset.

Formatting

- Given:

```
auto tp = system_clock::now();
auto tz = locale_zone("Europe/Berlin");
```

- Examples:

```
cout << format("{:%d.%m.%Y %T}\n",
               zoned_time{tz, floor<seconds>(tp)});
```

```
14.11.2019 11:13:40
```

Seconds-precision eliminates decimal point.

Formatting

- All of these types can be formatted:

zoned_time
local_time
sys_time

duration
year_month_day
year_month_day_last

month_day
year
month
day
weekday

file_time
hh_mm_ss
weekday_indexed
year_month
weekday_last
utc_time

gps_time
year_month_weekday
sys_info

tai_time
year_month_weekday_last
local_info

month_day_last
month_weekday_last
month_weekday

Parsing

- In general, if you can `std::format` it, you can `std::chrono::parse` it back in, usually with the same formatting string.

```
system_clock::time_point tp;
cin >> parse("%d.%m.%Y %T%z", tp);
cout << tp << '\n';
```

```
 Input:    14.11.2019 11:13:40.785346+0100
Output:    2019-11-14 10:13:40.785346
```

Clocks

- C++11 introduced system_clock, steady_clock and high_resolution_clock.
- Each clock has its own family of time_points
- A family of time_points allows different precisions, but not different clocks.
- Arithmetic within a family of time_points results in a time_point or duration with a precision computed by the common_type of the precision of the arguments.
- Arithmetic among different families of time_points is a compile-time error.

Clocks

- system_clock measures the time of day and the date.
- steady_clock is a stop watch no relationship to a calendar.
- high_resolution_clock is typically a type alias of steady_clock or system_clock.

Clocks

- C++20 adds:
  - file_clock
  - utc_clock
  - gps_clock
  - tai_clock

Clocks

```
file_clock
```

```
template<class Duration>
  using file_time = time_point<file_clock, Duration>;
```

- `file_clock` is the same type as `std::file_system::file_time_type::clock`.
- `file_clock`'s epoch is unspecified.
- `file_time_type` is returned from functions such as `file_system::last_write_time(const path& p)`.
- `file_time` can be cast to `sys_time` (and vice-versa) via `clock_cast`:

```
auto tp = clock_cast<system_clock>(last_write_time("/path"));
last_write_time("/path", clock_cast<file_clock>(tp));
```

Clocks

```
utc_clock

template<class Duration>
  using utc_time = time_point<utc_clock, Duration>;
```

- `utc_time` is just like `sys_time` except that it counts leap seconds.
- Useful when subtracting `time_points` across a leap second insertion point and 1s accuracy is required.
- `clock_cast` can be used to convert among `utc_time`, `file_time` and `sys_time`.
- `utc_clock::now()` is allowed but not required to be accurate during a leap second insertion.
- formatting and parsing `utc_time` allows for 61s in a minute, but only for a utc_time that is actually referencing a leap second insertion.

Clocks

```
gps_clock
```

```
template<class Duration>
  using gps_time = time_point<gps_clock, Duration>;
```

- `gps_time` measures time since `Sunday[1]/January/1980` 00:00:00 UTC.
- Useful for dealing with time points in the "GPS-shifted" civil calendar.
- `clock_cast` can be used to convert among `gps_time`, `utc_time`, `file_time` and `sys_time`.
- `gps_clock::now()` is allowed but not required to be fed from a GPS receiver.
- formatting and parsing `gps_time` maps to a civil time that is currently 18s ahead of `sys_time` and `utc_time`, and gets another second ahead with each added leap second.

Clocks

```
tai_clock

template<class Duration>
  using tai_time = time_point<tai_clock, Duration>;
```

- `tai_time` measures time since `1958y/1/1` 00:00:00 and is offset 10s ahead of UTC at this date.
- Useful for dealing with time points in the "TAI-shifted" civil calendar.
- `clock_cast` can be used to convert among `tai_time`, `gps_time`, `utc_time`, `file_time` and `sys_time`.
- `tai_clock::now()` is allowed but not required to be accurate during a leap second insertion.
- formatting and parsing `tai_time` maps to a civil time that is always 19s ahead of `gps_time`.

Clocks

```
time_point<A_clock, Duration>
clock_cast<A_clock>(time_point<B_clock, Duration> tp);
```

- User-written clocks can add support to participate in the `clock_cast` system with O(1) amount of code (independent of the number of clocks supporting `clock_cast`).
- Once `clock_cast` is supported by a user-written clock, that clock can `clock_cast` bidirectionally to *every* clock that supports `clock_cast`.

Library Design

- Library Design is an engineering process.
  - Both an art and a science.
- There are always tradeoffs to be made among conflicting goals.
- It is an iterative process, as is all engineering.

Library Design

- It is an iterative process, as is all engineering.
  - The first car wasn't Ferrari Enzo.
  - It was a tricycle with a motor attached.
  - It took many years and iterations for engineering technology to evolve from one to another.
  - So it goes with software.

Library Design

- And we're still early in the maturing of this industry.
- Study other's code.
- Learn from past successes.
- Learn even more from failures.

Library Design

- Detect as many errors as you can at compile-time.
- Make client code as readable as possible.
- Eliminate ambiguities in client code.
- Encourage your client to write efficient code.
- Offer both low-level and high-level access.
  - Low-level access emphasizes uncompromising performance and flexibility.
  - High-level access emphasizes convenience for common cases.

Library Design

- If you only take away one thing from this talk...
  - The readability of the code your clients write is far more important than the readability of your library's synopsis or header.

Q & A

Thank you for your time.