Sane Modern Special Member Functions

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Sane and Safe C++ Class Types

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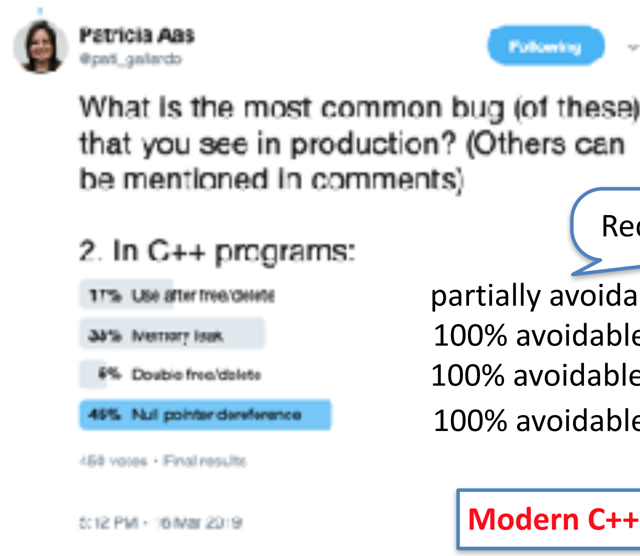
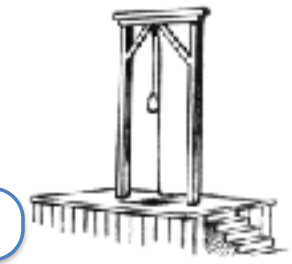
Typical C++ problems ?

C bugs are 100% avoidable in modern C++, except for dangling





Requires Discipline!

partially avoidable: values instead of pointers, references, views

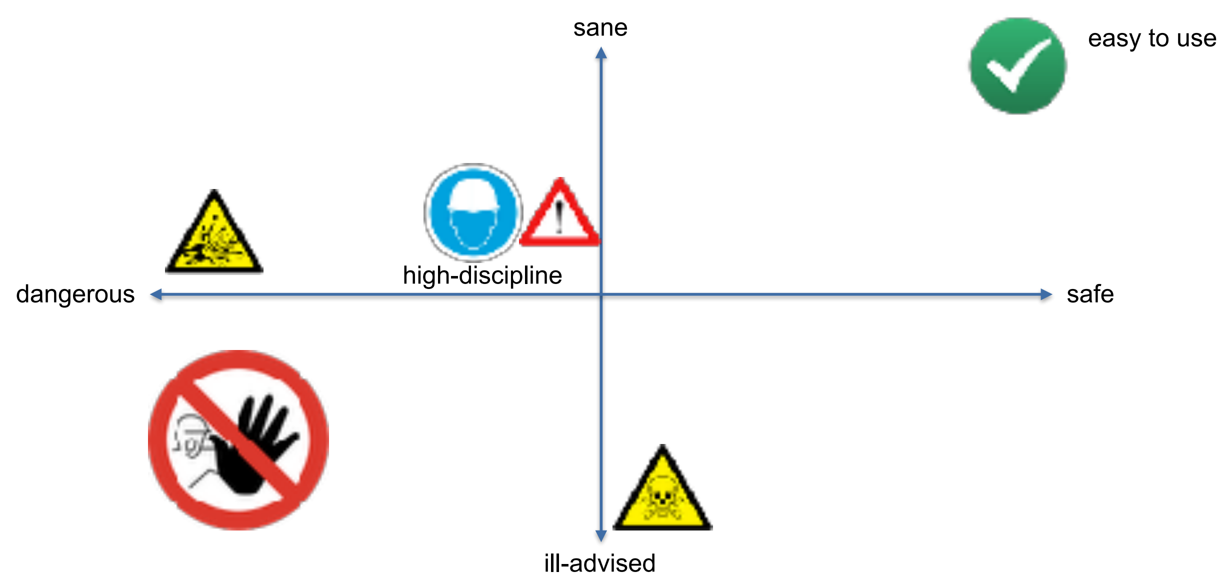
100% avoidable: unique_ptr, containers, or values

100% avoidable: unique_ptr, containers, or values

100% avoidable: values, references, checks (gsl::not_null)

Modern C++: NO PLAIN POINTERS or C-ARRAYS

except tightly encapsulated


sane
easy to use
high-discipline
dangerous
safe
ill-advised

Safe and sane user-defined class types

- **Value Types**
- **Empty Types**
- **Managing Types (different flavors)**
- **OO-polymorphic-hierarchy Types**

- **semi-sane: "potentially dangling object types" aka "pointing types"**

Rules for Special Member Functions

- **Rule of Zero**
  - Write your classes that you can rely on the compiler provided ones
- **Rule of Three**
  - Scott Meyer's classic: When you define either the destructor or a copy operation, define all three
  - variation: declare copy operations private to prevent slicing
- **Rule of Five/Six**
  - Scott Meyers extended for C++11: one for all, all for one (including default ctor)
- **Rule of DesDeMovA**
  - stay tuned.

Values

"When in doubt, do as the ints do!"
 -- Scott Meyers

"But may be not always..."
 -- Peter Sommerlad

C++ standard containers assume (semi-)regular types as template arguments for elements.
They might work with non-default constructible or move-only types but with limited functionality.

👍 **Just Works™**

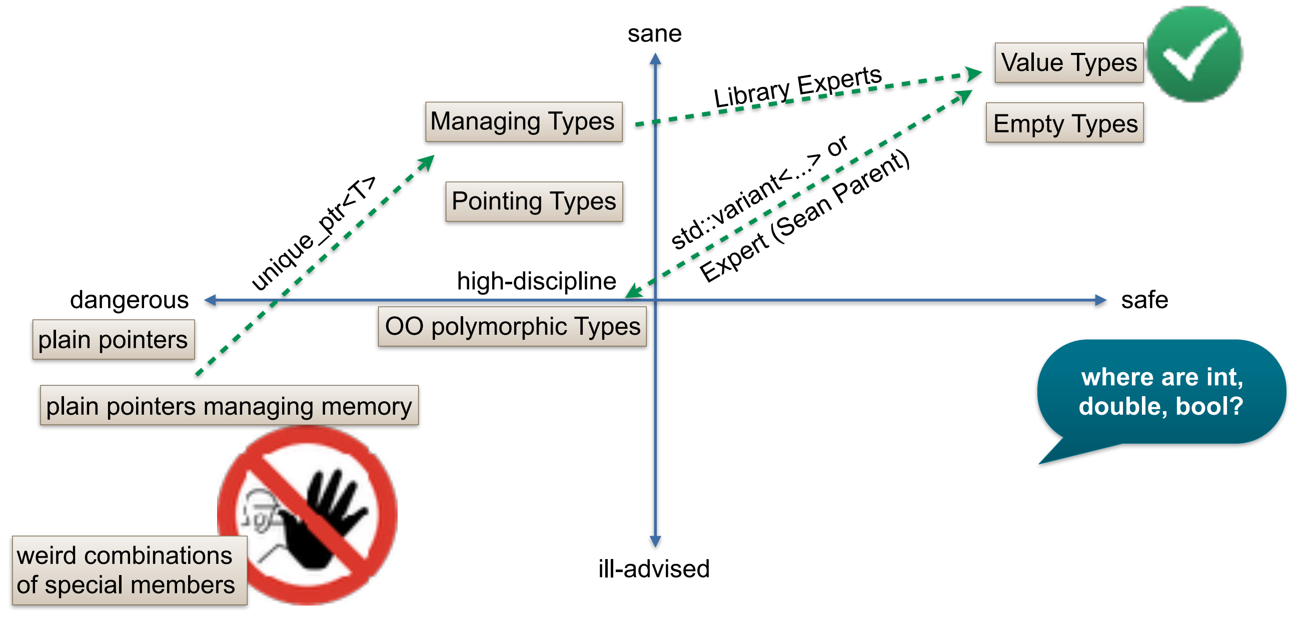
- **Properties of types satisfying concept Regular<T>**
  - EqualityComparable (==, !=)
  - DefaultConstructible T{}
  - Copyable T(T const&), T& operator=(T const&)&,
  - Movable T(T&&), T& operator=(T&&)&, is_object_v
  - Swappable swap(T&,T&)
  - Assignable t1 = t2
  - MoveConstructible T(T&&)

Sometimes Ordering is also required
std::less<T> should work,
usually by defining
bool operator<(T,T)

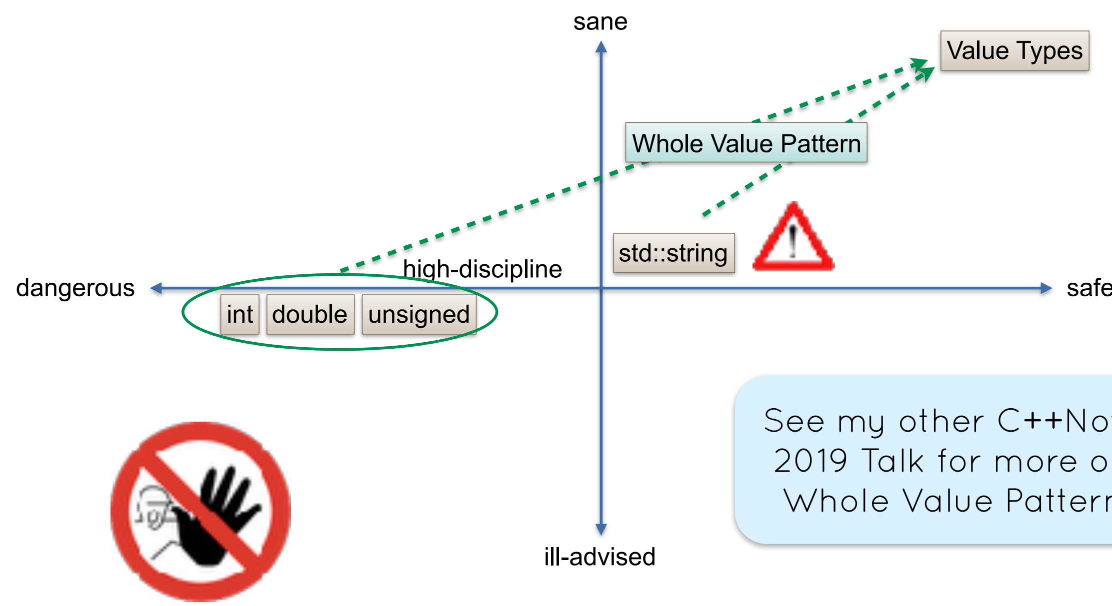
If comparison works, it should be consistent!
C++20 will make that **differently**,
through the "spaceship" operator<=>

Can the deriving class make private/protected members of a base class public?
Private inheritance is useful for mix-in base classes that only have friend functions. Otherwise they probably indicate a design-issue. Inheritance has high coupling!

Value (class) Types are Sane and Safe!



Dimensions Safety and Sanity...



See my other C++Now 2019 Talk for more on Whole Value Pattern

Should I make a (whole) value type default-constructible? T()=default;

- **Yes, whenever there is a natural default or neutral value in your type's domain**
  - int{} == 0
  - Be aware that the neutral value can depend on the major operation: int{} is not good for multiplication
- **May be, when initialization can be conditional and you need to define a variable first**
  - consider learning how to use ?: operator or an in-place called lambda, requires assignability otherwise
- **No, when there is not natural default value**
  - PokerCard (2-10, J, Q, K, Ace of ♤♧♡♢) What should be the default? - no default constructor!
- **No, when the type's invariant requires a reasonable initialization**
  - e.g., class CryptographicKey --> to be useful needs real key data

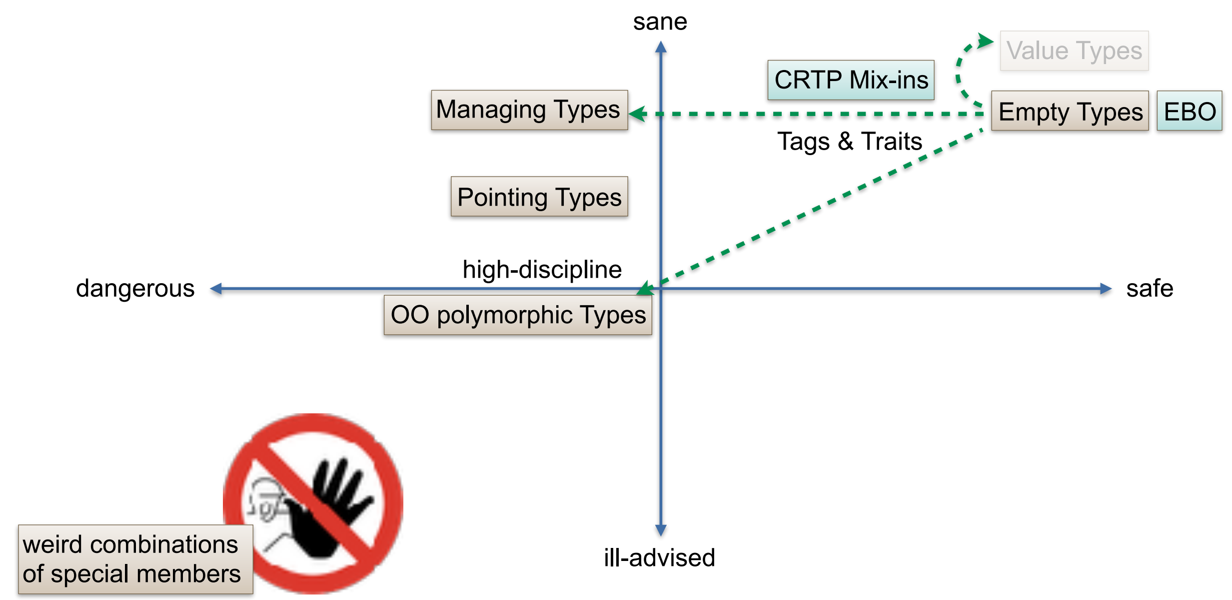
Empty Classes - useful?

"Oh you don't get something for nothing"
-- Rush

"Something for Nothing" -- Kevlin Henney, 1999

With a C++ Empty Class
you get something for nothing!

Dimensions Safety and Sanity...



- **Iterator Tags**
  - `input_iterator_tag`, `output_iterator_tag`, `forward_iterator_tag`, `bidirectional_iterator_tag`, `random_access_iterator_tag`
- **in place marker: `in_place_t`**
  - `std::in_place` global value

```
template< class... Args >
constexpr explicit
optional( std::in_place_t, Args&&... args );


// calls std::string( size_type count, CharT ch ) constructor
std::optional<std::string> o5(std::in_place, 3, 'A');
```

```
template< class BDIter >
void alg(BDIter, BDIter, std::bidirectional_iterator_tag)
{
    std::cout << "alg() called for bidirectional iterator\n";
}
template <class RAIter>
void alg(RAIter, RAIter, std::random_access_iterator_tag)
{
    std::cout << "alg() called for random-access iterator\n";
}
template< class Iter >
void alg(Iter first, Iter last)
{
    alg(first, last,
        typename std::iterator_traits<Iter>::iterator_category());
}
int main()
{
    std::vector<int> v;
    alg(v.begin(), v.end());

    std::list<int> l;
    alg(l.begin(), l.end());

//    std::istreambuf_iterator<char> i1(std::cin), i2;
//    alg(i1, i2); // compile error: no matching function for call
}
```

- `nullptr_t` and `nullptr` are similar but built-in

- **represent values as types**
  - integral_constant<T,T v>
    - true_type, false_type
  - ratio<5,3>
  - integer_sequence<T, T...vs>
- **What for?**
- **SFINAE**
  - template specialization selection
  - overload selection
- **Periods/scale in duration (ratio)**
- **tuple element access (integer_sequence)**

```
template<class T, T v>
struct integral_constant {
    using value_type=T;
    static constexpr value_type value = v;
    using type=integral_constant; // injected-class-name
    constexpr operator value_type() const noexcept {
        return value; }
    constexpr value_type operator()() const noexcept {
        return value; }
};
using true_type=integral_constant<bool,true>;

static_assert(integral_constant<bool,true>::value,"");
static_assert(true_type::value,"member access");
static_assert(true_type{},"auto-conversion");
static_assert(true_type{}(),"call operator");
static_assert(std::is_same_v<true_type, true_type::type>,
     "type meta");
```

- **determine type properties ..._v**
  - constexpr bool variable template
- **often used in generic code**
  - static_assert to check argument properties
  - SFINAE with enable_if
  - determining noexcept status
    - if constexpr (is_nothrow_movable<T>)
  - when type is not specified (auto variables) used with decltype(var)
- **classic implementation used inheritance from either true_type and false_type**
  - C++17: variable templates for _v versions

```
void demonstrate_type_queries(){
  using namespace std;
  ASSERT(is_integral_v<int>);
  ASSERT(not is_integral_v<double>);
  ASSERT(is_reference_v<int&>);
  ASSERT(not is_object_v<
    decltype(demonstrate_type_queries)>);
  ASSERT(is_object_v<int>);
  ASSERT(not is_object_v<int&>);
}
```

```
template <typename T>
struct Sack{
  static_assert(std::is_object_v<T> && !std::is_pointer_v<T>,
      "you can not use Sack with references or pointers");
};
Sack<int> sack;
//Sack<int*> ptrsack;// does not compile
//Sack<int&> refsack;// does not compile
```

- **compute new types ..._t**
- **get to the template argument's guts**
  - remove_xxxx_t, decay_t
- **adapt integral types**
  - make_unsigned_t, make_signed_t
- **build up needed types in generic code**
  - add_xxx_t
- **classic versions (without _t) exist, but you need to use typename and ::type**
  - `using S=typename make_signed<U>::type;`

```
using X=int const volatile[5];
using X1=remove_all_extents_t<X>;
ASSERT((is_same_v<X1,int const volatile>));
using X2=remove_cv_t<X1>;
ASSERT((is_same_v<X2,int>));
using RCV=int const volatile &; // cv ref to plain
ASSERT((is_same_v<int,decay_t<RCV>>));
using FR=void(&)(int); // func to funcptr
ASSERT((is_same_v<void(*)(int),decay_t<FR>>));
using AR=int const [42]; // array to ptr
ASSERT((is_same_v<int const *,decay_t<AR>>));

using I=decltype(42L);
using U=make_unsigned_t<I>;

using Tref=add_lvalue_reference_t<T>;
using Tcref=add_const_t<Tref>;
using Tptr=add_pointer_t<T>;
```

Empty class speciality: EBO Empty Baseclass Optimization

- **a class without members has at least size 1**
- **but not if it is used as a base class**
  - unless the derived type starts with a member of the same type
- **Often used to optimize away size**
  - see unique_ptr with default_delete or with my suggested default_free class instead of using a function pointer for free
  - also good for (CRTP-)Mix In classes, so they do not enlarge the object unnecessarily
- **C++20 adds that possibility even for "empty" members**
  - `[[no_unique_address]]` attribute

```
struct empty{};
static_assert(sizeof(empty)>0,
  "there must be something");

struct plain{
  int x;
};
static_assert(sizeof(plain)==sizeof(int),
  "no additional overhead");

struct combined : plain, private empty{
};
static_assert(sizeof(combined)==sizeof(plain),
  "empty base class should not add size");
```

When EBO does not work

- **a class without members has at least size 1**
- **but not if it is used as a base class**
  - unless the derived type starts with a member of the same type
  - each subobject of the same type must then have a unique address
- **For EBO to work nicely, have the first base hold the member(s) and further bases refer to it**
- **In addition use CRTP to ensure that each type differs**
- **It helps to check with static_assert**
  - duplicate empty bases break EBO precondition

```
struct empty{};
static_assert(sizeof(empty)>0
  && sizeof(empty)<sizeof(int),
  "there should be something");

struct ebo : empty{
  empty e;
  int i; // aligned to int
};
static_assert(sizeof(ebo)==2*sizeof(int),
  "ebo must not work");

struct noebo: empty{
  ebo e;
  int i;
};
static_assert(sizeof(noebo)==4*sizeof(int),
  "subojects must have unique addresses");
```

A glimpse of PSST (Peter's Simple Strong Typing) - EBO and CRTP-Mix-ins


```cpp
template <typename V, typename TAG>
struct strong {
   using value_type=V;
   V val;
};

template <typename U>
struct Eq{
   friend constexpr bool
   operator==(U const &l, U const& r) noexcept {
      auto const &[vl]=l;
      auto const &[vr]=r;
      return {vl == vr};
   }
   friend constexpr bool
   operator!=(U const &l, U const& r) noexcept {
      return !(l==r);
   }
};
template <typename U>
struct Inc{
   friend constexpr auto operator++(U &rv) noexcept {
      auto &[val]=rv;
      ++val;
      return rv;
   }
   friend constexpr auto operator++(U &rv,int) noexcept {
      auto res=rv;
      ++rv;
      return res;
   }
};
template <typename U>
struct Out {
   friend std::ostream&
   operator<<(std::ostream &l, U const &r) {
      auto const &[v]=r;
      return l << v;
   }
};
template <typename U, template <typename ...> class ...BS>
struct ops:BS<U>...{};

struct WaitC:strong<unsigned,WaitC>
            ,ops<WaitC,Eq,Inc,Out>{};
static_assert(sizeof(unsigned)==sizeof(WaitC));
void testWaitCounter(){
   WaitC c{};
   WaitC const one{1};
   ASSERT_EQUAL(WaitC{0},c);
   ASSERT_EQUAL(one,++c);
   ASSERT_EQUAL(one,c++);
   ASSERT_EQUAL(3,c.val);
}
```

aggregate

structured bindings

DANGER

delete via base pointer

CRTP and EBO Mixin

no overhead

See my other C++Now 2019 Talk for more details

- **An optimal unique_ptr specialization for C-style pointers requiring free**

```
inline std::string plain_demangle(char const *name){
   if (!name) return "unknown";
   char const *toBeFreed = abi::__cxa_demangle(name,0,0,0);
   std::string result(toBeFreed?toBeFreed:name);
   ::free(const_cast<char*>(toBeFreed));
   return result;
}
```

code from CUTE

```
inline std::string plain_demangle(char const *name){
   if (!name) return "unknown";
   std::unique_ptr<char const, decltype(&std::free)>
   toBeFreed { abi::__cxa_demangle(name,0,0,0), &std::free};
   std::string result(toBeFreed?toBeFreed:name);
   return result;
}
```

```
struct free_deleter{
   template <typename T>
   void operator()(T *p) const {
      std::free(const_cast<std::remove_const_t<T>*>(p));
   }
};
template <typename T>
using unique_C_ptr=std::unique_ptr<T,free_deleter>;

static_assert(sizeof(char *)==sizeof(unique_C_ptr<char>),"");
// compiles!

inline std::string plain_demangle(char const *name){
   if (!name) return "unknown";
   unique_C_ptr<char const>
      toBeFreed {abi::__cxa_demangle(name,0,0,0)};
   std::string result(toBeFreed?toBeFreed.get():name);
   return result;
}
```

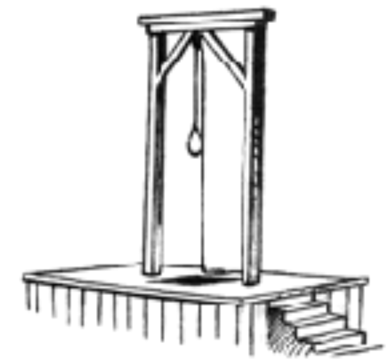
- **"invalid" inheritance, sometimes violating Liskov Substitution Principle**
  - but OK, if only extending or adapting functionality and never sliced to base class
  - inherits constructors from base - C++11 made those adapters much more practical
- **requires discipline in use, should never implicitly "downgraded" (upcasted)**
  - slicing harmful then, beware of use in code taking the base class type as parameter
  - If you use this to strengthen the invariant, e.g., a SortedVector inheriting from std::vector, very high discipline required, better wrap then!

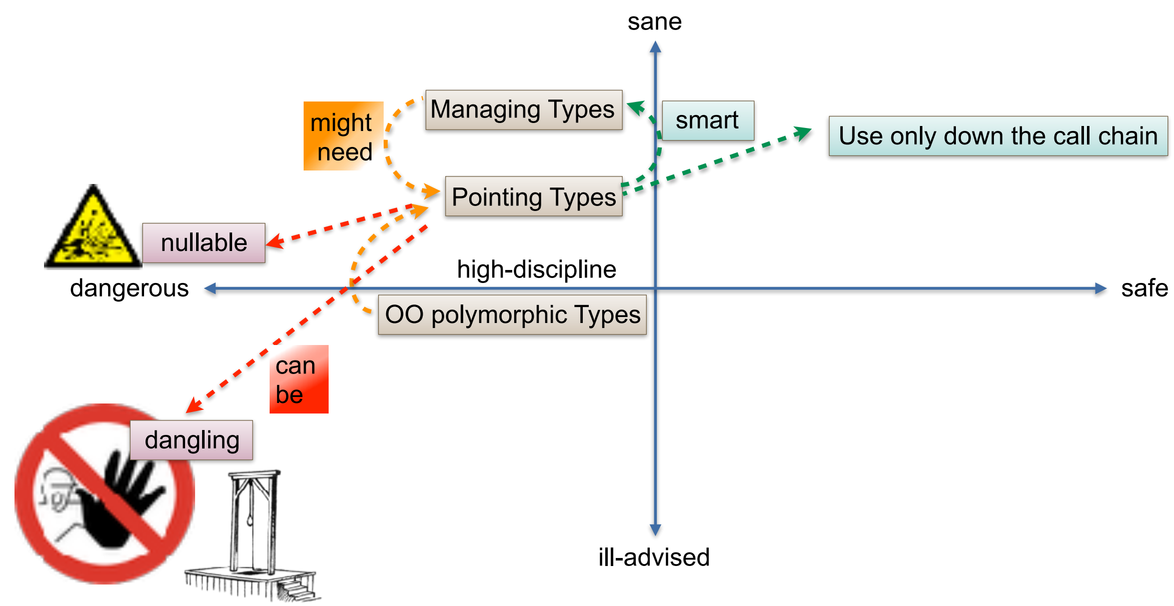
```
template<typename T, typename CMP=std::less<T>>
class indexableSet : public std::set<T,CMP>{
  using SetType=std::set<T,CMP>;
  using size_type=int;
public:
  using std::set<T,CMP>::set;

  T const & operator[](size_type index) const {
    return at(index);
  }
  T const & at(size_type index) const {
    if (index < 0) index += SetType::size();
    if (index < 0 || index >= SetType::size())
        throw std::out_of_range{"indexableSet:"};
    return *std::next(this->begin(),index);
  }
  T const & front() const {
    return at(0);
  }
  T const & back() const {
    return at(-1);
  }
};
```

"I just wanted to point to something"
Jonathan Müller (@foonathan), ACCU 2018

"C++ provides a rich set of types whose objects may dangle…We call these types potentially dangling. If a referred object's lifetime ends before the referring object, one risks undefined behavior."
(paraphrased from WG21-SG12/WG23 workshop in Kona 2019)




sane
Managing Types
smart
Use only down the call chain
might need
Pointing Types
nullable
dangerous
high-discipline
safe
OO polymorphic Types
can be
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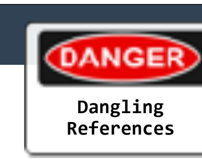
ill-advised

"Pointing" (class) Types



- C++ allows to define types that refer to other objects
- This means life-/using-time of the referring object needs not to extend the lifetime of the referred
- While often Regular, those types are not Value Types
  - they do not exist "out of time and space"
- References
- Iterators
- Pointers
- Reference Wrapper
- Views and Spans (std::string_view!)

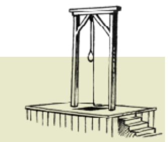
Iterators - Regular but not Values - they are potentially dangling types

- **Iterators satisfy concept Regular<T>, except for the need of DefaultConstructible**
  - istream(buf)_iterators have a special "eof" value, that is default constructed
- **Most iterators refer to other objects in containers**
  - relationship to the "pointed to" object as well as the container
  - changing the container can invalidate an iterator, but not always
  - dual role: reference to an object (e.g., find() result) and iteration

- **special iterator values (non-dereferencable):**
  - past the end-of-sequence iterator (end()) or before begin-of-sequence (forward_list::before_begin())
  - "singular" iterators (nullptr)
  - invalidated iterators due to changes in the container
  - Do not rely on iterator staying valid if a container's content can change

Usually invalid iterators can not be detected: UB

Can the deriving class make private/protected members of a base class public?
Private inheritance is useful for mix-in base classes that only have friend functions. Otherwise they probably indicate a design-issue. Inheritance has high coupling!



- **role: re-assignable lvalue (const) reference**
  - is not "nullable"! But can be dangling!
- **can be used for class members to keep class "regular"**
  - T& as a member disables assignment
- **can be used in container to refer to elements in other container**
  - use a container of (indices) into other container
- **implicitly converts to reference**
  - or access via get()
- **wraps function references**
  - overloads operator()
- **Factory functions: std::ref(T&), std::cref(T const&)**

```
template <class T>
class reference_wrapper {
public:
  // types
  typedef T type;

  // construct/copy/destroy
  reference_wrapper(T& ref) noexcept : _ptr(std::addressof(ref)) {}
  reference_wrapper(T&&) = delete;
  reference_wrapper(const reference_wrapper&) noexcept = default;

  // assignment
  reference_wrapper& operator=(const reference_wrapper& x)
    noexcept = default;

  // access
  operator T& () const noexcept { return *_ptr; }
  T& get() const noexcept { return *_ptr; }

  template< class... ArgTypes >
  std::invoke_result_t<T&, ArgTypes...>
    operator() ( ArgTypes&&... args ) const {
    return std::invoke(get(), std::forward<ArgTypes>(args)...);
  }

private:
  T* _ptr;
};
```

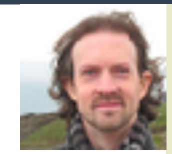
Most Smart Pointers - are no "potentially dangling types"

- **observer_ptr<T> better: jss::object_ptr<T>**
  - "borrows" object, does not own pointee
  - library fundamentals TS v2 (not std)
  - [object_ptr - a safer replacement for raw pointers]
- **unique_ptr<T> - can not dangle!**
  - owns pointee, cleans afterwards
- **shared_ptr<T>, weak_ptr<T> - can not dangle!**
  - shared ownership
  - overhead for atomic counting
  - may "pseudo-leak", even when weak_ptr pseudo-dangles

```
template <typename T>
using observer_ptr=T *;
```

My current recommendation:
- prefer unique_ptr<T> for heap-allocated objects
- for sharing keep unique_ptrs in a managing container and use references or reference_wrapper or object_ptr
- absolutely NO plain pointers with arithmetic (as in C)

jss::object_ptr<T> or my derived clone safecpp::object_ptr<T>



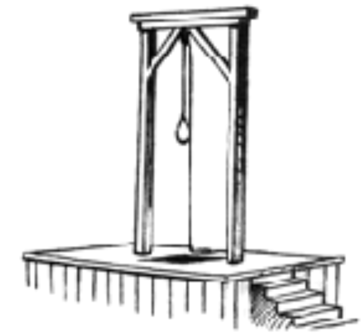
- **Prevent pointer arithmetic**
- **Clarify (non-) ownership**
- **implicit convert from smart and plain pointers to allow passing them seamlessly to functions**
- **replace T* parameters with object_ptr<T>**
  - mark such code that you already cared about it
- **Core Guidelines are wrong wrt T***
  - denoting T* as non-owning

```cpp
template <typename T> struct object_ptr {
    constexpr object_ptr() noexcept : ptr(nullptr) {}
    constexpr object_ptr(std::nullptr_t) noexcept : ptr(nullptr) {}
    constexpr object_ptr(T *ptr_) noexcept : ptr(ptr_) {}
    template <
        typename U,
        typename= std::enable_if_t<std::is_convertible_v<U *, T *>>>
    constexpr object_ptr(U *ptr_) noexcept : ptr(ptr_) {}

    template <
        typename Ptr,
        typename= std::enable_if_t<
            detail::is_convertible_smart_pointer_v<Ptr, T>>>
    constexpr object_ptr(Ptr const &other) noexcept : ptr(other.get()) {}

    constexpr T *get() const noexcept {
        return ptr;
    }
    constexpr T &operator*() const noexcept {
        return *ptr;
    }
    constexpr T *operator->() const noexcept {
        return ptr;
    }
    constexpr explicit operator bool() const noexcept {
        return ptr != nullptr;
    }
    constexpr explicit operator T *() const noexcept {
        return ptr;
    }
    constexpr bool operator!() const noexcept {
        return !ptr;
    }
    void reset(T *ptr_= nullptr) noexcept {
        ptr= ptr_;
    } // some omissions for brevity
private:
    T *ptr;
};
```

Views and Spans - Range-References for contiguous memory

- **References to contiguous sequences (e.g., from std::vector, std::array, std::string)**
- **Naming is contentious**
  - does a view allow changing the elements? --> span does
- **today: std::string_view**
  - std::string, std::array<char, N>, std::vector<char>
  - caveat: almost all of std::string bloated interface, except for mutation of characters
  - pure read-only, idea to replace (char const *) function parameters, but existing overloads :-(
- **C++20 (and core guidelines support library): span<T, int Extent>**
  - contention: static (compile-time) vs. dynamic extent (run-time)
  - allows mutation of elements
  - replacement for (T* , size_t len) function interfaces (C)

High-performance computing people define span<> to support multi-dimensional array views with mutable elements (P0546)



- **As a parameter type for functions that do not copy, save or change a string**
  - If read-only string processing is required
- **enables calling with C-style (char array) strings and std::string**
  - safer than (char const *)
  - better performance than (std::string const &)
  - beware of generic overloads when replacing existing APIs
    - might need overloads for all available character types (string_view, wstring_view) - no CharT deduction possible
    - I tried for the standard and failed!
- **In practice much less useful than I originally thought**
  - std::string pass-by-value often better when serious processing is required
- **Do never return std::string_view!**

C-style pointers: T*, T const *, T[] - also a potentially dangling types

- **Always define pointer variables const**
  - absolutely no pointer arithmetic!!!!!
  - especially for pointer parameters
- **Sidestep plain C-style pointers completely in user code**
- **Absolutely NO C-style arrays, because they are pointers in disguise**
  - they degenerate to pointers and require pointer arithmetic!
  - even built-in operator[] is pointer arithmetic!

```
int demo(int *const pi){
  //*pi++;
  (*pi)++;
  return *pi;
}
```


```
void dont_demo(int *const pi){
   1[pi]=42;
   pi[0]=41;
}
void testDont(){
   std::array<int,2> a{};
   dont_demo(a.data());
   std::initializer_list<int> exp{41,42};
   ASSERT_EQUAL_RANGES(begin(exp),end(exp),begin(a),end(a));
}
```

What to do about it?

- **All "pointing" Types live in the "dangerous" half**
- **High programmer discipline required**
- **Unfortunately code compiles**
  - often for backward compatibility
  - rules for iterator invalidation are subtle and rely on knowing implementation details
    - changing a container breaks code
    - Do not rely on iterator staying valid if a container's content can change
- **Ideas exist for static analysis (-> Herb Sutter)**
  - it is safe to pass them down the call chain
  - it is often unsafe to use them if you do not control the lifetime of the pointee

- **problem with reverse adapter for range for (CPPCon 2018 ⚡ Talk)**
  - https://github.com/PeterSommerlad/ReverseAdapter
  - init-statements with additional variable is just too ugly, IMHO

- **Just an idea (may be worth a ISO C++ paper?)**
  - provide deleted overloads for begin(), end() etc for rvalue references.
  - might break already wrong code
  - members returning elements by reference should return by value for temporaries


```
void testTemporaryArrayAccess(){
   ASSERT_EQUAL(2,(std::array{1,2,3}).at(1));
   int &i = std::array{2,3}[0];
   i=1; // UB
}
void testBeginTemporaryShouldNotCompile(){
   auto it = std::array{1,2,3}.begin();
   ASSERT_EQUAL(1,*it);
}
```

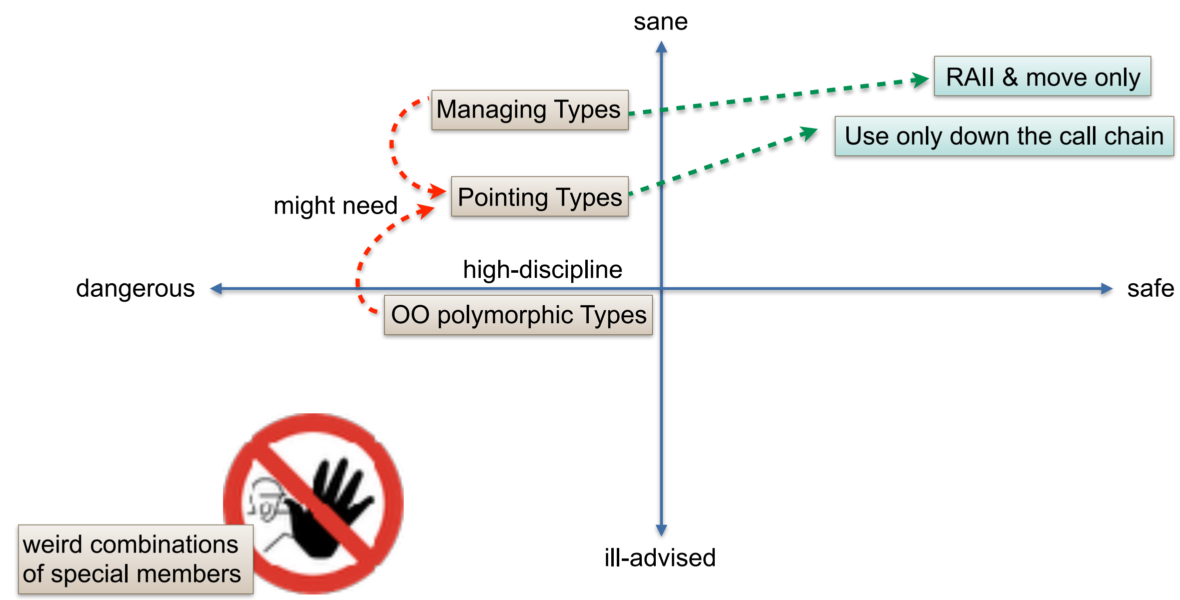
```
constexpr iterator
begin() & noexcept
{ return iterator(data()); }
constexpr const_iterator
begin() const & noexcept
{ return const_iterator(data()); }
constexpr iterator
begin() && noexcept  = delete;
```

```
constexpr reference
operator[](size_type __n)  & noexcept
{ return _AT_Type::_S_ref(_M_elems, __n); }
constexpr const_reference
operator[](size_type __n) const & noexcept
{ return _AT_Type::_S_ref(_M_elems, __n); }
constexpr value_type
operator[](size_type __n) && noexcept
{ return std::move(_M_elems[__n]); }
```

Managing stuff

"monomorphic object types"
-- Richard Corden, PRQA

"SBRM - scope-based resource management"
-- a better name for RAII


sane
RAII & move only
Managing Types
Use only down the call chain
might need
Pointing Types
high-discipline
dangerous
safe
OO polymorphic Types
weird combinations
of special members
ill-advised

Managing types complexity staging

- **Common to Managing types**
  - define "interesting" destructor: `~manager() { /* clean up stuff */}`
- **0: scope - locally usable SBRM (e.g., `std::lock_guard`)**
  - Rule of **DesDeMovA**: `manager& operator=(manager &&) noexcept=delete;`
  - No movability implies also no copyability
  - C++17: can still return from factory if needed
- **1: unique - move-only type (e.g., `std::unique_ptr`)**
  - requires a **sane moved-from state** for transfer of ownership, copy operations implicitly deleted
- **N: value type (e.g., `std::vector`)**
  - requires duplicatable resource (aka memory)

Manager Design Pattern: Monomorphic Object Types (SBRM)

- **Instances of monomorphic object types have significant identity (they are not values)**
- **Copying and assignment is prohibited**
  - Factories can still return by value from a temporary (C++17!)
  - Apply "Rule of DesDeMovA"
- **Passed by Reference (or Pointer-like type)**
  - "long" lifetime, allocated high-up the call hierarchy or on heap
- **No virtual members, no inheritance (except for mix-ins)**
- **Roles**
  - manage other objects, i.e., contain a container of something: vector<unique_ptr<T>> as member
  - wrap hardware or stateful I/O
  - encapsulate other stateful behavior, e.g., context of State design pattern, Builder, Context Object

```
struct ScreenItems{
  void add(widget w){
    content.push_back(std::move(w));
  }
  void draw_all(screen &out){
    for(auto &drawable:content){
      drawable->draw(out);
    }
  }
private:
  ScreenItems& operator=(ScreenItems &&) noexcept
     =delete; // all others deleted, except default
  widgets content{};
};
static_assert(!std::is_copy_constructible_v<ScreenItems>,"no copying");
static_assert(!std::is_move_constructible_v<ScreenItems>,"no moving");
ScreenItems makeScreenItems(){
  return ScreenItems {}; // must be a temporary
}
```


ev Beispiel Flux Compensator

Use existing RAII (Resource Acquisition Is Initialization) for SBRM

- **OK, make_unique() (**and make_shared) **for heap allocation.**
- **What else?**
- **Use std-library RAII classes, e.g., string, vector, fstream, ostringstream, thread, unique_lock**
- **Use boost-library RAII classes, if needed, e.g., boost.asio's tcp::iostream**

- **Don't write your own generic RAII!**
- ~~**wait for unique_resource<T,D>: http://wg21.link/p0052**~~
  - You can help with me https://github.com/PeterSommerlad/scope17

Dynamic Polymorphism

"inheritance is the base class of Evil"
-- Sean Parent, Adobe

Do you Remember: What Special Member Functions Do You Get?

What you get

What you write	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted (!)	defaulted (!)	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted (!)	not declared	not declared
copy assignment	defaulted	defaulted	defaulted (!)	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared
move assignment	defaulted	defaulted	deleted	deleted	not declared	user declared

Howard Hinnant's Table: https://accu.org/content/conf2014/Howard_Hinnant_Accu_2014.pdf
Note: Getting the defaulted special members denoted with a (!) is a bug in the standard.

Making a OO base class T non-copyable: T& operator=(T&&) noexcept=delete;

What you get

What you write

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted (!)	defaulted (!)	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted (!)	not declared	not declared
copy assignment	defaulted	defaulted	defaulted (!)	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared
move assignment	defaulted	defaulted	deleted	deleted	not declared	user declared

Howard Hinnant's Table: https://accu.org/content/conf2014/Howard_Hinnant_Accu_2014.pdf
Note: Getting the defaulted special members denoted with a (!) is a bug in the standard.

Rule of DesDeMovA: `T& operator=(T&&) noexcept=delete;`

DesDeMovA

Rule of if
Destructor defined
Deleted
Move **A**ssigment

What you write

	default constructor	[illegible]	[illegible]	py ment	move constructor	move assignment
nothing	defaulted	[illegible]	[illegible]	ulted	defaulted	defaulted
any constructor	not declared	[illegible]	[illegible]	ulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted (!)	defaulted (!)	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted (!)	not declared	not declared
copy assignment	defaulted	defaulted	defaulted (!)	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared
move assignment	defaulted	defaulted	deleted	deleted	not declared	user declared

Howard Hinnant's Table: https://accu.org/content/conf2014/Howard_Hinnant_Accu_2014.pdf
Note: Getting the defaulted special members denoted with a (!) is a bug in the standard.

Polymorphic Object Types -- think thrice about using virtual!

- **Base in class in hierarchy defines abstraction**
  - usually abstract (pure virtual destructor)
- **Instances of polymorphic object types have important identity**
- **Copying and assignment is prohibited (implicitly or explicitly) - non-Regular types**
- **Passed by Reference (or Pointer-like type)**
  - "long" lifetime, allocated up in the call hierarchy (best) or on the heap (doable)
- **Virtual member functions and (pure) virtual destructor in base class**
  - subclasses should not add additional virtual members, define pure virtual destructor of base
- Most other attempts with multiple layers of inheritance or even multiple inheritance are often futile

good OO design?

widget hierarchie?

Example taken from https://www.ibm.com/developerworks/library/ws-mapping-to-rdb/

Polymorphic Hierarchy example: Composite Design Pattern

```
struct drawable {
  virtual ~drawable()=0;
  virtual void draw(screen& on)=0;
protected:
  drawable&
operator=(drawable&&)noexcept=delete;
  // prohibit move and copy
};
drawable::~drawable()=default;
```

DesDeMovA

```
struct composite:drawable{
  composite()=default;
  void add(widget w){
    content.push_back(std::move(w));
  }
  void draw(screen &on){
    on << "{ ";
    for(auto &w:content){
      w->draw(on);
    }
    on << " }";
  }
private:
  widgets content{};
};
```

How are widget and widgets usefully defined?

```
struct rect:drawable{
  rect(Width w, Height h):
    width{w},height{h}{}
  void draw(screen& on){
    on << "rectangle:"
       << width << "," << height;
  }
  Width width;
  Height height;
};
```

```
struct circle:drawable{
  circle(Radius r):
    radius{r}{}
  void draw(screen& on){
    on << "circle:" << radius;
  }
  Radius radius;
};
```

```
struct drawable {
  virtual ~drawable()=0;
  virtual void draw(screen& on)=0;
protected:
  drawable&
operator=(drawable&&)noexcept=delete;
  // prohibit move and copy
};
drawable::~drawable()=default;
```

DesDeMovA 🙋

```
struct refcomposite:drawable{
  refcomposite()=default;
  void add(widget w){
    content.push_back(w);
  }
  void draw(screen &on){
    on << "{ ";
    for(drawable& w:content){
      w.draw(on);
    }
    on << " }";
  }
private:
  widgets content{};
};
```

How are widget and widgets usefully defined?

```
struct rect:drawable{
  rect(Width w, Height h):
    width{w},height{h}{}
  void draw(screen& on){
    on << "rectangle:"
       << width << "," << height;
  }
  Width width;
  Height height;
};
```

```
struct circle:drawable{
  circle(Radius r):
    radius{r}{}
  void draw(screen& on){
    on << "circle:" << radius;
  }
  Radius radius;
};
```

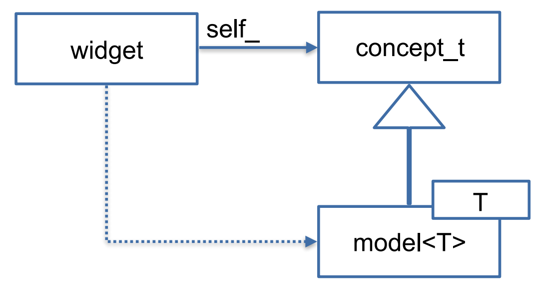
Type-erasure Object/Value dualities

- **An observation:**
  - `std::function<ret(params)> var;` // can store any kind of function matching signature
  - How?
- **`std::any some;` can store any value type**
  - can only access what was stored
    - and can be empty
  - often better `std::variant` when when set of possible types is known
    - a variant can not be empty
      - **except under exceptional condition**

```
void demoAny(){
  std::any some;
  ASSERT(!some.has_value());
  some = 42;
  ASSERT(some.has_value());
  ASSERT_EQUAL(42,std::any_cast<int>(some));
  some = 3.14;
  ASSERT_THROWS(std::any_cast<int>(some),std::bad_any_cast);
  some = "anything";
  ASSERT_EQUAL("anything",std::any_cast<char const*>(some));
}
```


any, function

- **Sean Parent: dynamic Polymorphism without inheritance**
  - make polymorphic stuff regular and extendible without inheritance
  - requires also a mechanism called "type erasure"
  - combines inheritance and templates internally
  - can store arbitrary values, like any
  - and provide interface to them
- **How?**




```
void testComposite(){
  std::ostringstream out{};
  composite c{};
  c.add(circle{Radius{42}});
  c.add(rect{Width{4},Height{2}});
  c.add(circle{Radius{4}});
  c.add(42);
  c.add("a c string");
  widget w{c};
  draw(w,out);
  ASSERT_EQUAL("{ circle:42,rectangle:"
   "4,2,circle:4,an_int:42,"
   "a c string, }",out.str());
}
```


any, function

Sean Parent's magical polymorphic Regular objects


```
struct widget {
  template<typename T>
  widget(T x)
  :self_(std::make_unique<model<T>>(std::move(x)))
  {}

  widget(widget const & x)
  : self_(x.self_->copy_()) {}
  widget(widget&&) noexcept = default;

  widget& operator=(widget const & x) {
    return *this = widget(x);
  }
  widget& operator=(widget&&) noexcept = default;

  friend void draw(widget const & x, screen& out)
  {
    x.self_->draw_(out);
  }

private:
  struct concept_t { // polymorphic base
    virtual ~concept_t() = default;
    virtual std::unique_ptr<concept_t>
      copy_() const = 0;
    virtual void draw_(screen&) const = 0;
  };
  template<typename T>
  struct model: concept_t {
    model(T x) :
        data_(std::move(x)) {
    }
    std::unique_ptr<concept_t> copy_() const {
      return std::make_unique<model>(*this);
    }
    void draw_(screen& out) const {
      draw(data_, out);
    }

    T data_;
  };
  std::unique_ptr<concept_t> self_;
};
using widgets=std::vector<widget>;
```


any, function

```
struct rect{
  rect(Width w, Height h):
    width{w},height{h}{}
  Width width;
  Height height;
};

void draw(rect const &r, screen& on){
  on << "rectangle:" << r.width
  << "," << r.height;
}

struct circle{
  circle(Radius r):
    radius{r}{}
  Radius radius;
};
void draw(circle const &c, screen& on){
  on << "circle:" << c.radius;
}
```

```
struct composite{
  void add(widget w){
    content.emplace_back(std::move(w));
  }
  friend void
  draw(composite const &c, screen &on){
    on << "{ ";
    for(widget const &drawable:c.content){
      draw(drawable, on); on << ',';
    }
    on << " }";
  }
private:
  widgets content{};
};

void testRect(){
  std::ostringstream out{};
  widget r{rect{Width{2},Height{4}}};
  draw(r,out);
  ASSERT_EQUAL("rectangle:2,4",out.str());
}
```


any, function

		Some constructor	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Aggregates		none	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Simple Values		yes	none / =default	defaulted	defaulted	defaulted	defaulted	defaulted
Scope	Manager	typical	none / =default	implemented	deleted	deleted	deleted	=delete 🙋
Unique	Manager	typical	defined / =default	implemented	deleted	deleted	implemented	implemented
Value	Manager	yes	defined / =default	implemented	implemented	implemented	implemented	implemented
OO - Base		may be	may be	=default virtual!	deleted	deleted	deleted	=delete 🙋
OO & Value Sean Parent		yes	no	Expert Level - =default	Expert Level Implementation	Expert Level Implementation	Expert Level Implementation	Expert Level Implementation

We want Rule of Zero to Rule!

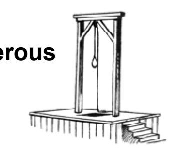
But what do we get, when we apply it?

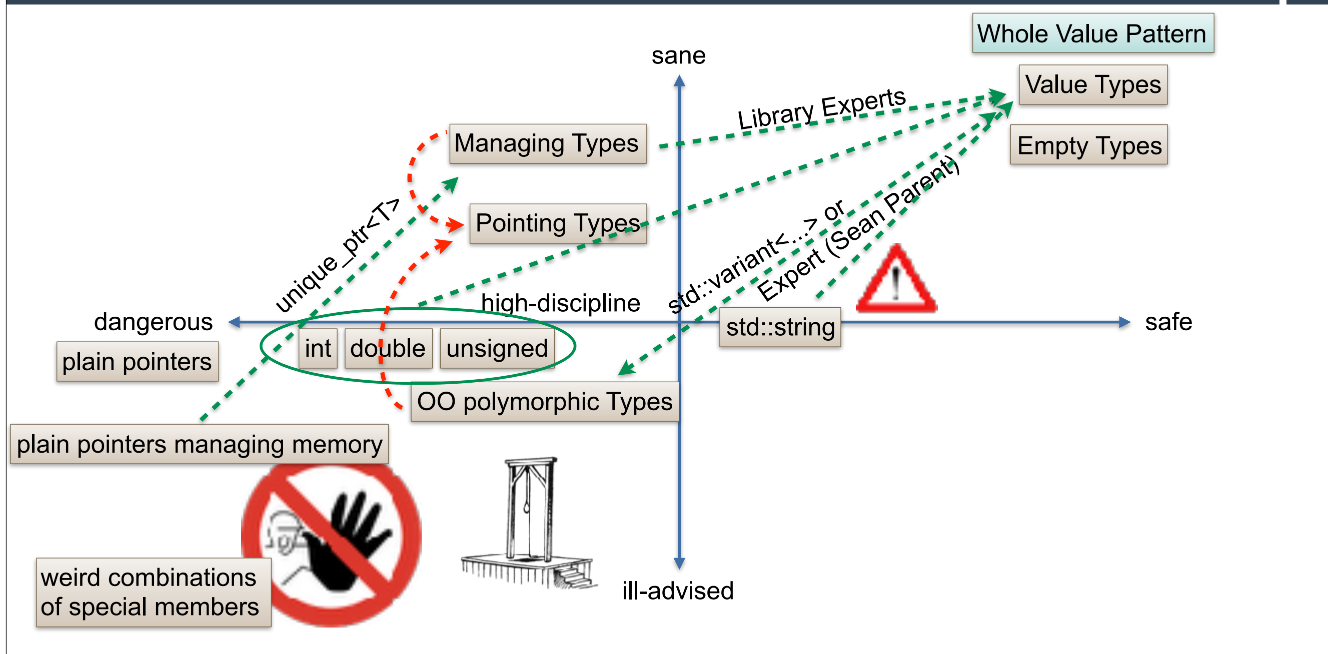
**We want to apply the Rule of Zero
because
Code that is not there can not be wrong**

Influence of Member Variable Types on Special Member Functions

Member Varible Kind	Some constructor	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Value	none	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
T&[2]	yes	=delete	defaulted	defaulted	=delete[1]	defaulted	=delete[1]
[2] Scope Manager	typical	none	defaulted	deleted	deleted	deleted	deleted
[2] Unique Manager	typical	defined / =default	defaulted	deleted	deleted	defaulted	defaulted
Pot. Dangling[2,3]	typical	defined / =default	defaulted	defaulted	defaulted	defaulted	defaulted

- **1 - remedy through using std::reference_wrapper<T> instead**
- **2 - "contagious": your class becomes the same without further means**
- **3 - Regular Potentially Dangling Members make using your class type dangerous**



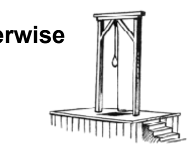


Whole Value Pattern
sane
Value Types
Library Experts
Managing Types
Empty Types
unique_ptr<T>
Pointing Types
std::variant<...> or
Expert (Sean Parent)
high-discipline
dangerous
safe
int
double
unsigned
std::string
plain pointers
OO polymorphic Types
plain pointers managing memory
weird combinations
of special members
ill-advised

Summary

- **Rule of Zero**
  - for value types, for types with managing members
- **Rule of DesDeMovA**
  - for OO base classes, for SBRM classes

- **Adapted Rule of Three (destructor and move operations)**
  - for unique managing types
- **Rule of Five**
  - for expert-level managing types (Containers like vector, Type Erasure, others)
- **Avoid members of potentially dangling types, otherwise**



increasing complexity

- **Model with Value Types almost always**
- **Wrap primitives using Whole Value, even a named simple struct communicates better than** int (see my other talk, just a reminder!)
- **Be aware of the required expertise and discipline for Manager types and OO hierarchies**
  - Remember "**Rule of DesDeMovA**"
  - **and make yourself and your environment familiar with it**
- **Be very disciplined about using Pointing types, this includes references and string_view**
  - Member variables that can potentially dangle make your type potentially dangling as well!
- **Run away from types with weird special member function combinations, even if defaulted**
  - usually they attempt to do too much or the wrong thing -> REFACTOR!