
# Fun with Type Erasure:

## Implementing a Value Wrapper for Polymorphic Types

Pavel Novikov

# Fun with type erasure:

## implementing a value wrapper for polymorphic types

Pavel Novikov

@cpp_ape

R&D Align Technology

# We'll discuss

- a *very* brief refresher on polymorphism and pointer semantics
- most basic value wrapper using `std::any`
  - and its drawbacks for this application
- minimal implementation of value wrapper
  - *very* economical (best *value* for your bytes!) (get it?)
  - with small object optimization
- what else can we do?
  - saving pointer to interface
  - supporting move, copy assign and move assign
- adding other features
  - emplace, and assignment from values

# We'll discuss

- a *very* brief refresher on polymorphism and pointer semantics
- most basic value wrapper using `std::any`
  - and its drawbacks for this application
- minimal implementation of value wrapper
  - *very* economical (best *value* for your bytes!) (get it?)
  - with small object optimization
- what else can we do?
  - saving pointer to interface
  - supporting move, copy assign and move assign
- adding other features
  - emplace, and assignment from values

# We'll discuss

- a *very* brief refresher on polymorphism and pointer semantics
- most basic value wrapper using `std::any`
  - and its drawbacks for this application
- minimal implementation of value wrapper
  - *very* economical (best *value* for your bytes!) (get it?)
  - with small object optimization
- what else can we do?
  - saving pointer to interface
  - supporting move, copy assign and move assign
- adding other features
  - emplace, and assignment from values

# We'll discuss

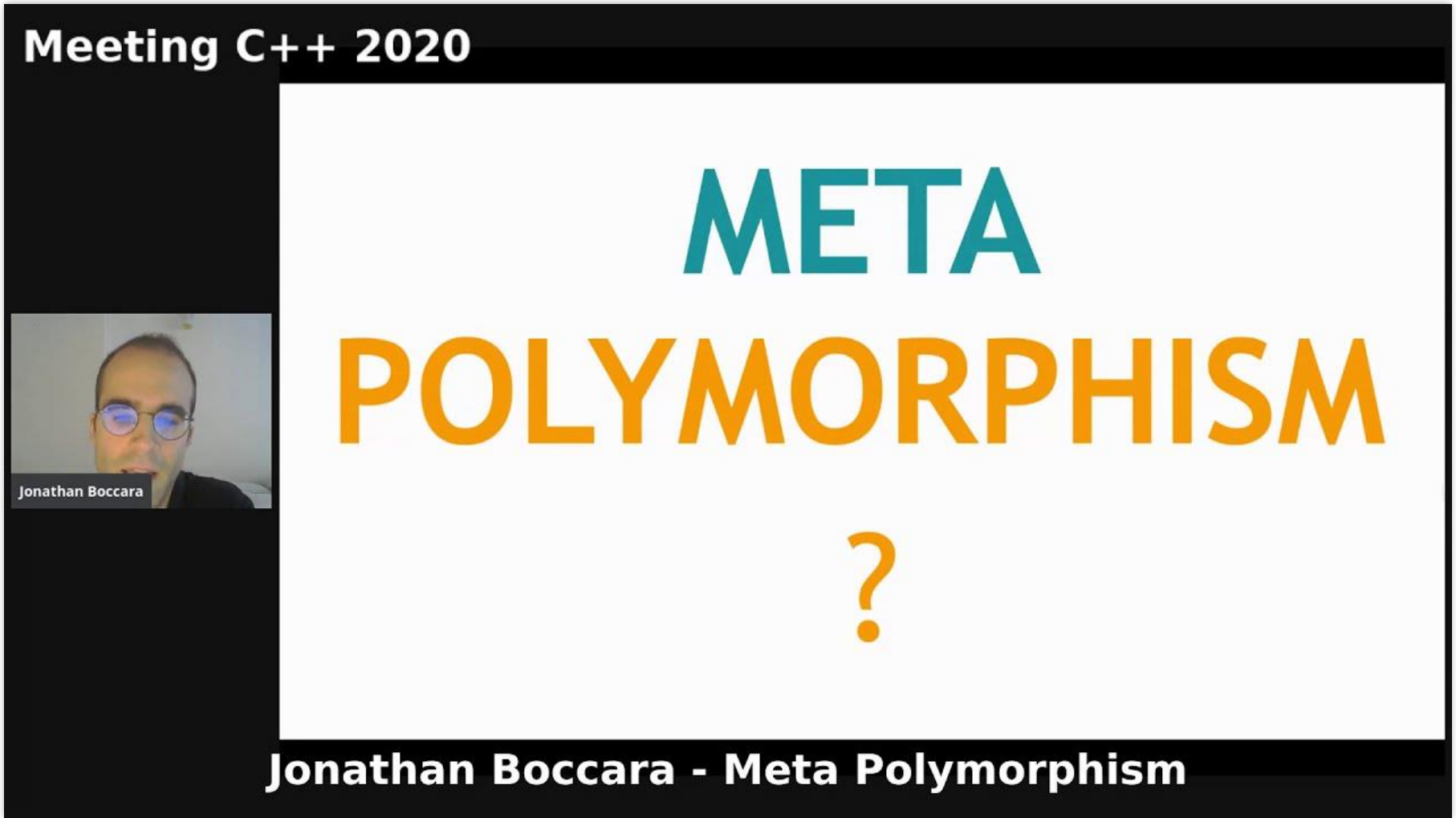
- a *very* brief refresher on polymorphism and pointer semantics
- most basic value wrapper using `std::any`
  - and its drawbacks for this application
- minimal implementation of value wrapper
  - *very* economical (best *value* for your bytes!) (get it?)
  - with small object optimization
- what else can we do?
  - saving pointer to interface
  - supporting move, copy assign and move assign
- adding other features
  - emplace, and assignment from values

# We'll discuss

- a *very* brief refresher on polymorphism and pointer semantics
- most basic value wrapper using `std::any`
  - and its drawbacks for this application
- minimal implementation of value wrapper
  - *very* economical (best *value* for your bytes!) (get it?)
  - with small object optimization
- what else can we do?
  - saving pointer to interface
  - supporting move, copy assign and move assign
- adding other features
  - emplace, and assignment from values

# The idea

https://www.youtube.com/watch?v=mU_n_ohIHQk



# Pointer semantics

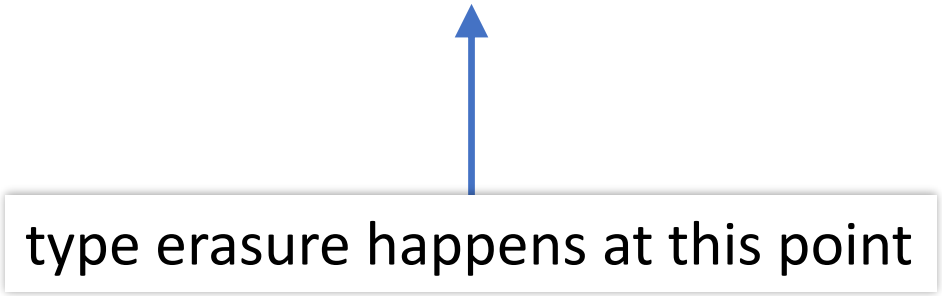
```
struct Shape {
   virtual void draw() = 0;
   virtual void changeSize(float sx, float sy) = 0;
   virtual ~Shape() = default;
};
```

# Pointer semantics

```
struct Ellipse : Shape {
  void draw() override;
  void changeSize(float sx, float sy) override;
};

struct Rectangle : Shape {
  void draw() override;
  void changeSize(float sx, float sy) override;
};

struct Star : Shape {
  void draw() override;
  void changeSize(float sx, float sy) override;
};
```

# Pointer semantics

```
std::unique_ptr<Shape> s = std::make_unique<Star>();
```



# Pointer semantics

```
std::unique_ptr<Shape> s = std::make_unique<Star>();
```

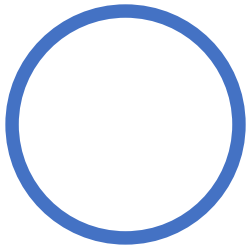
- pointer/reference semantics
- generally **can not** copy/clone values
- generally has to use memory allocation

# Pointer semantics

```
std::vector<std::unique_ptr<Shape>> shapes;
```

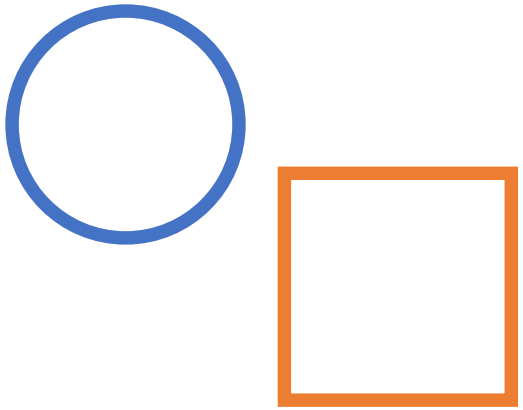
# Pointer semantics

```
std::vector<std::unique_ptr<Shape>> shapes;
shapes.push_back(std::make_unique<Ellipse>());
```



# Pointer semantics

```
std::vector<std::unique_ptr<Shape>> shapes;
shapes.push_back(std::make_unique<Ellipse>());
shapes.push_back(std::make_unique<Rectangle>());
```



# Pointer semantics

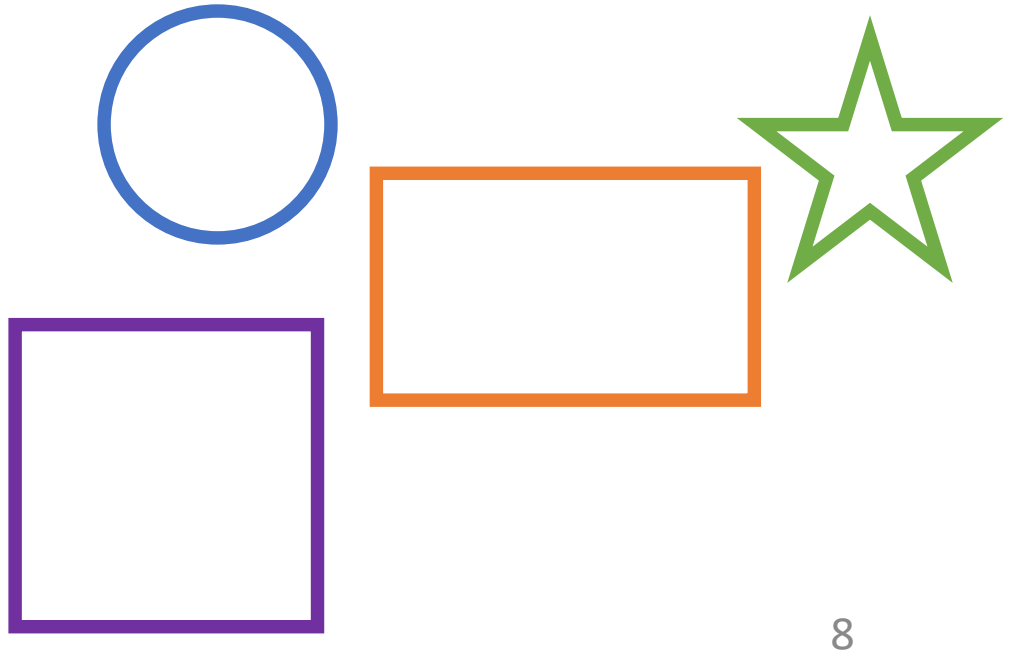
```
std::vector<std::unique_ptr<Shape>> shapes;
shapes.push_back(std::make_unique<Ellipse>());
shapes.push_back(std::make_unique<Rectangle>());
shapes.push_back(std::make_unique<Star>());
```

# Pointer semantics

```
std::vector<std::unique_ptr<Shape>> shapes;
shapes.push_back(std::make_unique<Ellipse>());
shapes.push_back(std::make_unique<Rectangle>());
shapes.push_back(std::make_unique<Star>());

auto &shape1 = shapes[1];
shape1->changeSize(3.f, 5.f);
```

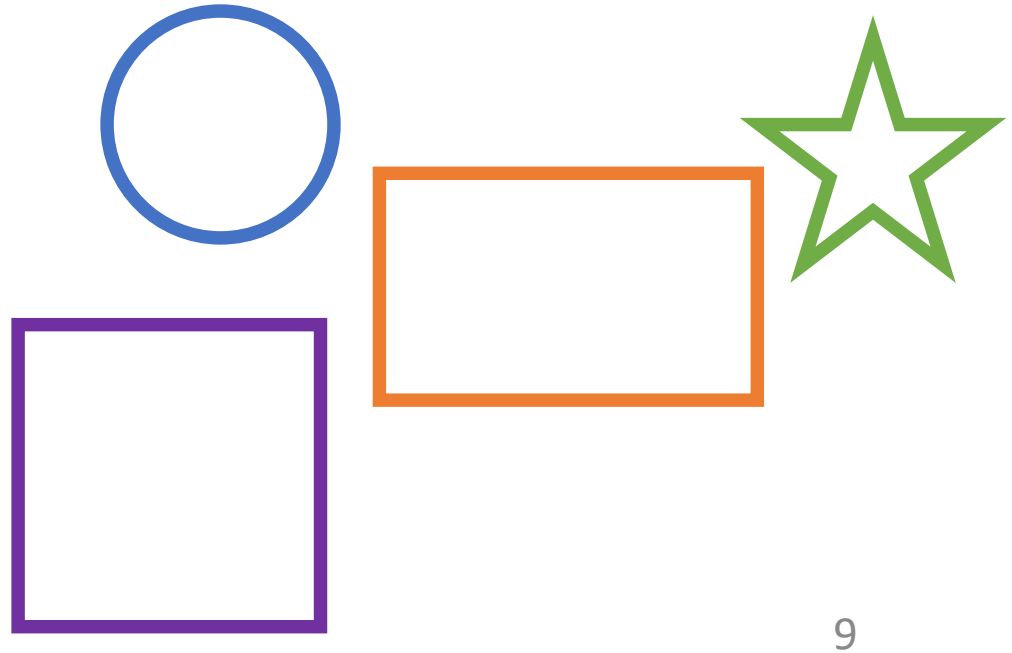
# Pointer semantics

```
std::vector<std::unique_ptr<Shape>> shapes;
shapes.push_back(std::make_unique<Ellipse>());
shapes.push_back(std::make_unique<Rectangle>());
shapes.push_back(std::make_unique<Star>());

auto &shape1 = shapes[1];
shape1->changeSize(3.f, 5.f);

auto clone = ???
clone.changeSize(4.f, 4.f);
```



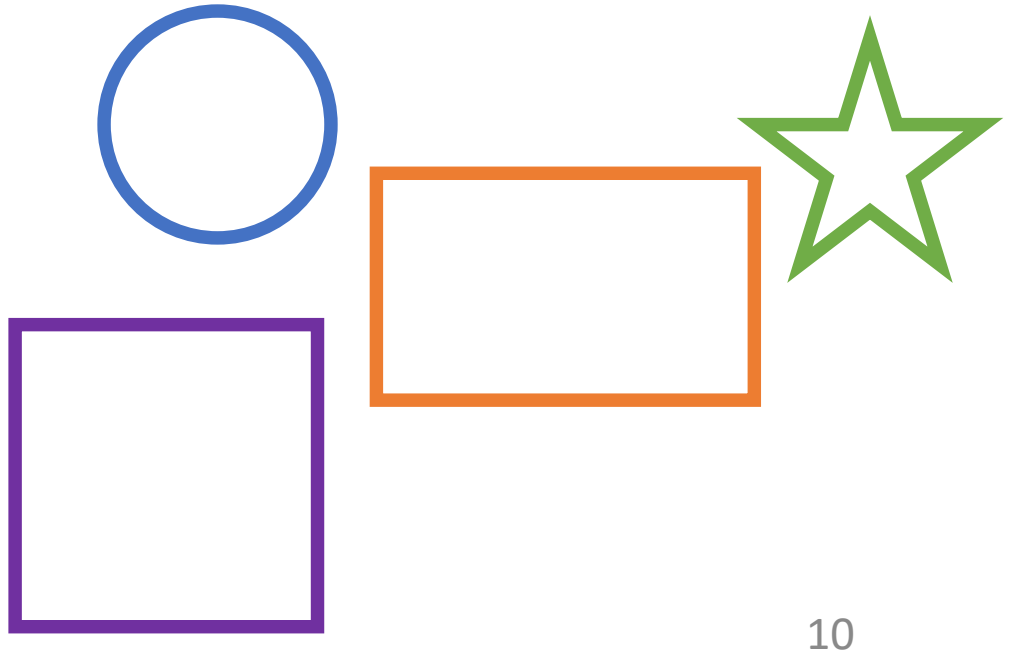
# Value semantics?

```
std::vector<ValueWrapper<Shape>> shapes;
shapes.push_back(ValueWrapper<Shape>{ Ellipse{} });
shapes.push_back(ValueWrapper<Shape>{ Rectangle{} });
shapes.push_back(ValueWrapper<Shape>{ Star{} });

auto &shape1 = shapes[1];
shape1.value().changeSize(2.f, 3.f);

auto clone = shape1;
clone.value().changeSize(3.f, 3.f);
```



# Value semantics?

```
std::vector<ValueWrapper<Shape>> shapes;
shapes.emplace_back(Ellipse{});
shapes.emplace_back(Rectangle{});
shapes.emplace_back(Star{});

auto &shape1 = shapes[1];
shape1.value().changeSize(2.f, 3.f);

auto clone = shape1;
clone.value().changeSize(3.f, 3.f);
```



# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
              !std::is_same_v<std::decay_t<T>, ValueWrapper>)
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
              !std::is_same_v<std::decay_t<T>, ValueWrapper>)
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
              !std::is_same_v<std::decay_t<T>, ValueWrapper>)
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T,
    std::enable_if_t<std::is_base_of_v<Interface, std::decay_t<T>> &&
      !std::is_same_v<std::decay_t<T>, ValueWrapper>>* = nullptr>
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
              !std::is_same_v<std::decay_t<T>, ValueWrapper>)
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
              !std::is_same_v<std::decay_t<T>, ValueWrapper>)
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
              !std::is_same_v<std::decay_t<T>, ValueWrapper>)
  explicit ValueWrapper(T &&object) //...
  //...
  Interface &value() { /*...*/ }
  const Interface &value() const { /*...*/ }
  bool hasValue() const { /*...*/ }
private:
  std::any data;
  const Interface &(*getter)(const std::any &) = nullptr;
};
```

# Basic solution

```
//...
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
            !std::is_same_v<std::decay_t<T>, ValueWrapper>)
explicit ValueWrapper(T &&object) :
  data{ std::forward<T>(object) },
  getter{
    [](const std::any &a)->const Interface& {
      return std::any_cast<const std::decay_t<T>&>(a);
    } }
{}
//...
```

# Basic solution

```
//...
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
            !std::is_same_v<std::decay_t<T>, ValueWrapper>)
explicit ValueWrapper(T &&object) :
  data{ std::forward<T>(object) },
  getter{
    [](const std::any &a)->const Interface& {
      return std::any_cast<const std::decay_t<T>&>(a);
    } }
{}
//...
```

# Basic solution

```
//...
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>> &&
            !std::is_same_v<std::decay_t<T>, ValueWrapper>)
explicit ValueWrapper(T &&object) :
  data{ std::forward<T>(object) },
  getter{
    [](const std::any &a)->const Interface& {
      return std::any_cast<const std::decay_t<T>&>(a);
    } }
{}
//...
```

# Basic solution

```
//...
Interface &value() {
  return const_cast<Interface&>(getter(data));
}
const Interface &value() const {
  return getter(data);
}

bool hasValue() const {
  return data.has_value();
}
//...
```

# Basic solution

```
//...
Interface &value() {
  return const_cast<Interface&>(getter(data));
}
const Interface &value() const {
  return getter(data);
}

bool hasValue() const {
  return data.has_value();
}
//...
```

# Basic solution

```
//...
Interface &value() {
  return const_cast<Interface&>(getter(data));
}
const Interface &value() const {
  return getter(data);
}

bool hasValue() const {
  return data.has_value();
}
//...
```

# Basic solution

| | |
|---|---|
| init | `auto v = ValueWrapper<Shape>{ Star{} };` |
| copy/clone | `auto x = v;` |
| move | `auto y = std::move(v);` |
| copy assign | `x = y;` |
| move assign | `x = std::move(y);` |
| using underlying value | `x.value().changeSize(3.f, 3.f);` |

# Basic solution: drawbacks

```
const Interface &operator->() const {
  return getter(data);
}
//...
  getter{
    [](const std::any &a)->const Interface& {
      return std::any_cast<const std::decay_t<T>&>(a);
    } }
//...
```

calling by function pointer

**run-time** type check
+ another type "un-erasure" call to get a reference

# Basic solution: drawbacks

`std::any` small object optimization:

| std lib | `sizeof(std::any)` | small object capacity |
|---|---|---|
| MSVC | 64 | `((6 + 16 / sizeof(void*)) - 2) * sizeof(void*) = 48`<br>(56 for trivial types) |
| libstdc++ | 16 | `sizeof(void*) = 8` |
| libc++ | 32 | `3 * sizeof(void*) = 24` |

* for x64

+ `sizeof(getter)` for `ValueWrapper`

# Basic solution: drawbacks

`std::any` small object optimization:

| std lib | `sizeof(std::any)` | small object capacity |
|---|---|---|
| MSVC | 64 | `((6 + 16 / sizeof(void*)) - 2) * sizeof(void*) = 48` (56 for trivial types) |
| libstdc++ | 16 | `sizeof(void*) = 8` |
| libc++ | 32 | `3 * sizeof(void*) = 24` |

* for x64

\+ `sizeof(getter)` for `ValueWrapper`

# Basic solution: drawbacks

`std::any` small object optimization:

| | small object capacity |
|---|---|
| std lib | |
| MSVC | `((6 + 16 / sizeof(void*)) - 2) * sizeof(void*) = 48` (56 for trivial types) |
| libstdc++ | `sizeof(void*) = 8` |
| libc++ | `3 * sizeof(void*) = 24` |

* for x64

+ `sizeof` apper

# Basic solution: drawbacks

`std::any` small object optimization:

small buffer
+ pointer to function table
+ pointer to type info

| std lib | `sizeof(std::any)` | small object capacity |
|---|---|---|
| MSVC | 64 | `((6 + 16 / sizeof(void*)) - 2) * sizeof(void*) = 48`<br>(56 for trivial types) |
| libstdc++ | 16 | `sizeof(void*) = 8` |
| libc++ | 32 | `3 * sizeof(void*) = 24` |

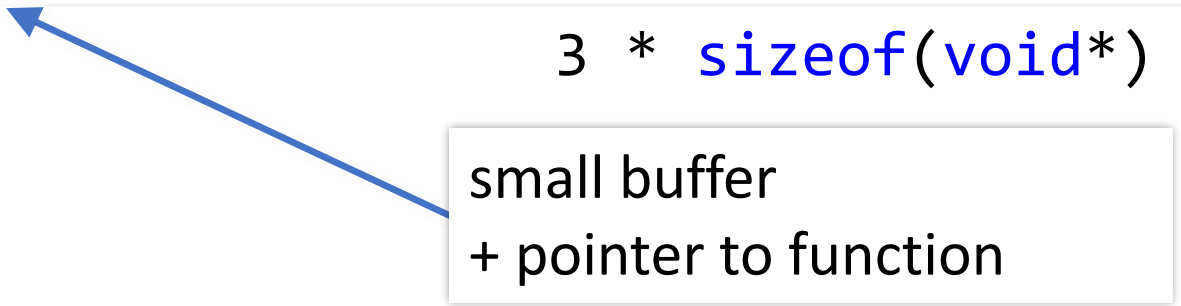
* for x64

+ `sizeof(getter)` for `ValueWrapper`

# Basic solution: drawbacks

`std::any` small object optimization:

| std lib | `sizeof(std::any)` | small object capacity |
|---|---|---|
| MSVC | 64 | `((6 + 16 / sizeof(void*)) - 2) * sizeof(void*) = 48`<br>(56 for trivial types) |
| libstdc++ | 16 | `sizeof(void*) = 8` |
| libc++ | 32 | `3 * sizeof(void*) = 24` |




* for x64

+ `sizeof(getter)` for `ValueWrapper`

# Basic solution: drawbacks

`std::any` small object optimization:

| std lib | `sizeof(std::any)` | small object capacity |
|---|---|---|
| MSVC | 64 | `((6 + 16 / sizeof(void*)) - 2) * sizeof(void*) = 48`<br>(56 for trivial types) |
| libstdc++ | 16 | `sizeof(void*) = 8` |
| libc++ | 32 | `3 * sizeof(void*) = 24` |

* for x64

+ `sizeof(getter)` for `ValueWrapper`

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  ValueWrapper() noexcept = default;
  template<typename T>
    requires (std::is_base_of_v<Interface, std::decay_t<T>>)
  explicit ValueWrapper(T &&object);
  ValueWrapper(const ValueWrapper &other);
  ~ValueWrapper();
  ValueWrapper &operator=(const ValueWrapper &other);
  Interface &value();
  const Interface &value() const;
  bool hasValue() const;
private:
  //...
};
```

# Minimal implementation

```
template<typename Interface>
struct ValueWrapper {
  //...
private:
  static constexpr size_t smallCapacity = 24;
  //...
  union {
    std::byte small[smallCapacity] = {};
    void *big;
  };
  struct Methods;
  const Methods *methods = nullptr;
  //...
};
```

small buffer + pointer

pointer to function table

```
//...
private:
  static constexpr size_t smallCapacity = 24;

  template<typename T>
  static constexpr bool isSmall =
    sizeof(T) <= smallCapacity &&
    alignof(T) <= alignof(void*);

  union {
    std::byte small[smallCapacity] = {};
    void *big;
  };
  //...
```

```
//...
private:
  static constexpr size_t smallCapacity = 24;

  template<typename T>
  static constexpr bool isSmall =
    sizeof(T) <= smallCapacity &&
    alignof(T) <= alignof(void*);

  union {
    std::byte small[smallCapacity] = {};
    void *big;
  };
  //...
```

```
//...
private:
  static constexpr size_t smallCapacity = 24;

  template<typename T>
  static constexpr bool isSmall =
    sizeof(T) <= smallCapacity &&
    alignof(T) <= alignof(void*);

  union {
    std::byte small[smallCapacity] = {};
    void *big;
  };
  //...
```

```
//...
private:
  static constexpr size_t smallCapacity = 24;

  template<typename T>
  static constexpr bool isSmall =
    sizeof(T) <= smallCapacity &&
    alignof(T) <= alignof(void*);

  union {
    std::byte small[smallCapacity] = {};
    void *big;
  };
  //...
```

```
//...
private:
  //...
  struct Methods {
    void (*destroy)(ValueWrapper &data) noexcept;
    void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
    const Interface &(*get)(const ValueWrapper &data) noexcept;
  };
  const Methods *methods = nullptr;

  template<typename T>
  static constexpr Methods getTableForSmallObject();

  template<typename T>
  static constexpr Methods getTableForBigObject();

  template<typename T>
  static constexpr Methods table =
    isSmall<T> ? getTableForSmallObject<T>() : getTableForBigObject<T>();
};
```

```
//...
private:
  //...
  struct Methods {
    void (*destroy)(ValueWrapper &data) noexcept;
    void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
    const Interface &(*get)(const ValueWrapper &data) noexcept;
  };
  const Methods *methods = nullptr;

  template<typename T>
  static constexpr Methods getTableForSmallObject();

  template<typename T>
  static constexpr Methods getTableForBigObject();

  template<typename T>
  static constexpr Methods table =
    isSmall<T> ? getTableForSmallObject<T>() : getTableForBigObject<T>();
};
```

```
//...
private:
  //...
  struct Methods {
    void (*destroy)(ValueWrapper &data) noexcept;
    void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
    const Interface &(*get)(const ValueWrapper &data) noexcept;
  };
  const Methods *methods = nullptr;

  template<typename T>
  static constexpr Methods getTableForSmallObject();

  template<typename T>
  static constexpr Methods getTableForBigObject();

  template<typename T>
  static constexpr Methods table =
    isSmall<T> ? getTableForSmallObject<T>() : getTableForBigObject<T>();
};
```

```
//...
private:
  //...
  struct Methods {
    void (*destroy)(ValueWrapper &data) noexcept;
    void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
    const Interface &(*get)(const ValueWrapper &data) noexcept;
  };
  const Methods *methods = nullptr;

  template<typename T>
  static constexpr Methods getTableForSmallObject();

  template<typename T>
  static constexpr Methods getTableForBigObject();

  template<typename T>
  static constexpr Methods table =
    isSmall<T> ? getTableForSmallObject<T>() : getTableForBigObject<T>();
};
```

```
//...
private:
  //...
  struct Methods {
    void (*destroy)(ValueWrapper &data) noexcept;
    void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
    const Interface &(*get)(const ValueWrapper &data) noexcept;
  };
  const Methods *methods = nullptr;

  template<typename T>
  static constexpr Methods getTableForSmallObject();

  template<typename T>
  static constexpr Methods getTableForBigObject();

  template<typename T>
  static constexpr Methods table =
    isSmall<T> ? getTableForSmallObject<T>() : getTableForBigObject<T>();
};
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *reinterpret_cast<const T*>(&v.small);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *reinterpret_cast<const T*>(&v.small);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *reinterpret_cast<const T*>(&v.small);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *reinterpret_cast<const T*>(&v.small);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *reinterpret_cast<const T*>(&v.small);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.big = new T{ *static_cast<const T*>(src.big) };
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *static_cast<const T*>(v.big);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.big = new T{ *static_cast<const T*>(src.big) };
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *static_cast<const T*>(v.big);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.big = new T{ *static_cast<const T*>(src.big) };
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *static_cast<const T*>(v.big);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.big = new T{ *static_cast<const T*>(src.big) };
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *static_cast<const T*>(v.big);
    }
  };
}
```

# Minimal implementation

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.big = new T{ *static_cast<const T*>(src.big) };
    },
    [](const ValueWrapper &v) noexcept ->const Interface& {//get
      return *static_cast<const T*>(v.big);
    }
  };
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper() noexcept = default;

template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    big = new std::decay_t<T>{ std::forward<T>(object) };
  }
}
```

# Minimal implementation

```
ValueWrapper(const ValueWrapper &other) :
  methods{ other.methods }
{
  if (methods)
    methods->copyConstruct(*this, other);
}

~ValueWrapper() {
  if (hasValue())
    methods->destroy(*this);
}
```

# Minimal implementation

```
ValueWrapper(const ValueWrapper &other) :
  methods{ other.methods }
{
  if (methods)
    methods->copyConstruct(*this, other);
}

~ValueWrapper() {
  if (hasValue())
    methods->destroy(*this);
}
```

# Minimal implementation

```
ValueWrapper(const ValueWrapper &other) :
  methods{ other.methods }
{
  if (methods)
    methods->copyConstruct(*this, other);
}

~ValueWrapper() {
  if (hasValue())
    methods->destroy(*this);
}
```

# Minimal implementation

```
ValueWrapper &operator=(const ValueWrapper &other) {
  if (&other == this)
    return *this;

  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }
  if (other.methods) {
    other.methods->copyConstruct(*this, other);
    methods = other.methods;
  }
  return *this;
}
```

needed to support self assignment

needed for weak exception guarantee

the order of assignment matters here

# Minimal implementation

```
ValueWrapper &operator=(const ValueWrapper &other) {
  if (&other == this)
    return *this;

  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }
  if (other.methods) {
    other.methods->copyConstruct(*this, other);
    methods = other.methods;
  }
  return *this;
}
```

needed to support self assignment

needed for weak exception guarantee

the order of assignment matters here

# Minimal implementation

```
ValueWrapper &operator=(const ValueWrapper &other) {
  if (&other == this)
    return *this;

  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }
  if (other.methods) {
    other.methods->copyConstruct(*this, other);
    methods = other.methods;
  }
  return *this;
}
```

needed to support self assignment

needed for weak exception guarantee

the order of assignment matters here

# Minimal implementation

```
ValueWrapper &operator=(const ValueWrapper &other) {
  if (&other == this)
    return *this;

  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }
  if (other.methods) {
    other.methods->copyConstruct(*this, other);
    methods = other.methods;
  }
  return *this;
}
```

needed to support self assignment

needed for weak exception guarantee

the order of assignment matters here

# Minimal implementation

```
Interface &value() {
  return const_cast<Interface&>(methods->get(*this));
}
const Interface &value() const {
  return methods->get(*this);
}

bool hasValue() const {
  return methods != nullptr;
}
```

# Minimal implementation

```
Interface &value() {
  return const_cast<Interface&>(methods->get(*this));
}
const Interface &value() const {
  return methods->get(*this);
}

bool hasValue() const {
  return methods != nullptr;
}
```

# Minimal implementation

```
Interface &value() {
  return const_cast<Interface&>(methods->get(*this));
}
const Interface &value() const {
  return methods->get(*this);
}

bool hasValue() const {
  return methods != nullptr;
}
```

# Minimal implementation

```
Interface &value() {
  return const_cast<Interface&>(methods->get(*this));
}
const Interface &value() const {
  return methods->get(*this);
}

bool hasValue() const {
  return methods != nullptr;
}
```

# Minimal implementation

```
Interface &value() {
  return const_cast<Interface&>(methods->get(*this));
}
const Interface &value() const {
  return methods->get(*this);
}

bool hasValue() const {
  return methods != nullptr;
}
```

# Minimal implementation

```
struct Impl : Iface {
  Impl() { std::cout << "Impl::ctor\n"; }
  Impl(const Impl &) { std::cout << "Impl::copy ctor\n"; }
  Impl(Impl &&) noexcept { std::cout << "Impl::move ctor\n"; }
  ~Impl() { std::cout << "Impl::dtor\n"; }
  Impl &operator=(const Impl &) { std::cout << "Impl::copy =\n"; return *this; }
  Impl &operator=(Impl &&) noexcept { std::cout << "Impl::move =\n"; return *this; }

  void foo() override {
    std::cout << "Impl::foo(): " << data << '\n';
  }

  char data[4] = "abc";
};
```

```
auto v = ValueWrapper<Iface>{ Impl{} };
```
```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```
```
Impl::copy ctor
```

```
auto y = std::move(v);
```
```
Impl::copy ctor
```

```
x = y;
```
```
Impl::dtor
Impl::copy ctor
```

```
x = std::move(y);
```
```
Impl::dtor
Impl::copy ctor
```

```
x->foo();
```
```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

```
auto v = ValueWrapper<Iface>{ Impl{} };
```

```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```

```
Impl::copy ctor
```

```
auto y = std::move(v);
```

```
Impl::copy ctor
```

```
x = y;
```

```
Impl::dtor
Impl::copy ctor
```

```
x = std::move(y);
```

```
Impl::dtor
Impl::copy ctor
```

```
x->foo();
```

```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

```
auto v = ValueWrapper<Iface>{ Impl{} };
```
```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```
```
Impl::copy ctor
```

```
auto y = std::move(v);
```
```
Impl::copy ctor
```

```
x = y;
```
```
Impl::dtor
Impl::copy ctor
```

```
x = std::move(y);
```
```
Impl::dtor
Impl::copy ctor
```

```
x->foo();
```
```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

# Let’s save pointer to interface

```
const Interface &value() const {
  return methods->get(*this);
}
```

# Let’s save pointer to interface

```
private:
  //...
  union {
    std::byte small[smallCapacity] = {};
    void *big;
  };

  struct Methods { /*...*/ };
  const Methods *methods = nullptr;

  Interface *interface = nullptr;
  //
```

# Let’s save pointer to interface

```
Interface &value() {
  return *interface;
}
const Interface &value() const {
  return *interface;
}
```

# Let’s save pointer to interface

```
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    interface =
      ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    auto *instance = new std::decay_t<T>{ std::forward<T>(object) };
    big = instance;
    interface = instance;
  }
}
```

# Let’s save pointer to interface

```
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    interface =
      ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    auto *instance = new std::decay_t<T>{ std::forward<T>(object) };
    big = instance;
    interface = instance;
  }
}
```

# Let’s save pointer to interface

```
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  if constexpr (isSmall<std::decay_t<T>>) {
    interface =
      ::new(small) std::decay_t<T>{ std::forward<T>(object) };
  }
  else {
    auto *instance = new std::decay_t<T>{ std::forward<T>(object) };
    big = instance;
    interface = instance;
  }
}
```

# Let’s save pointer to interface

```
struct Methods {
  void (*destroy)(ValueWrapper &data) noexcept;
  void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
};
```

# Let’s save pointer to interface

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.interface =
        ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    }
  };
}
```

# Let’s save pointer to interface

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      auto *instance = new T{ *static_cast<const T*>(src.big) };
      dst.big = instance;
      dst.interface = instance;
    }
  };
}
```

# Comparison to `std::any`

**MSVC** for x64

```
union {
  unsigned char _TrivialData[56];
  struct {
    union {
      unsigned char _Data[48];
      void* _Ptr;
    };
    const _Any___RTTI* _RTTI;
  };
};
uintptr_t _TypeData;
```

small buffer for trivial types

small buffer + pointer for other types

pointer to function table

pointer to type info packed with type category flag in the lower 2 bits

# Comparison to `std::any`

**MSVC** for x64

```
union {
  unsigned char _TrivialData[56];
  struct {
    union {
      unsigned char _Data[48];
      void* _Ptr;
    };
    const _Any___RTTI* _RTTI;
  };
};
uintptr_t _TypeData;
```

small buffer for trivial types

small buffer + pointer for other types

pointer to function table

pointer to type info packed with type category flag in the lower 2 bits

# Comparison to `std::any`

**MSVC** for x64

```
union {
  unsigned char _TrivialData[56];
  struct {
    union {
      unsigned char _Data[48];
      void* _Ptr;
    };
    const _Any___RTTI* _RTTI;
  };
};
uintptr_t _TypeData;
```

small buffer for trivial types

small buffer + pointer for other types

pointer to function table

pointer to type info packed with type category flag in the lower 2 bits

# Comparison to `std::any`

**libstdc++**

```
union _Arg {
  void *_M_obj;
  const std::type_info *_M_typeinfo;
  any *_M_any;
};
void (*_M_manager)(_Op, const any*, _Arg*);
union {
  void *_M_ptr;
  aligned_storage<sizeof(_M_ptr), alignof(void*)>::type _M_buffer;
};
```

pointer to "do-all" function

small buffer + pointer

# Comparison to `std::any`

**libstdc++**

```
union _Arg {
  void *_M_obj;
  const std::type_info *_M_typeinfo;
  any *_M_any;
};
void (*_M_manager)(_Op, const any*, _Arg*);
union {
  void *_M_ptr;
  aligned_storage<sizeof(_M_ptr), alignof(void*)>::type _M_buffer;
};
```

pointer to "do-all" function

small buffer + pointer

# Comparison to `std::any`

**libc++**

```
void *(*__h)(_Action,
             any const*,
             any*,
             const type_info*,
             const void *__fallback_info);
union {
  void *__ptr;
  aligned_storage_t<3 * sizeof(void*),
                    alignment_of<void *>::value> __buf;
};
```

pointer to "do-all" function

small buffer + pointer

# Comparison to `std::any`

**libc++**

```
void *(*__h)(_Action,
             any const*,
             any*,
             const type_info*,
             const void *__fallback_info);
union {
  void *__ptr;
  aligned_storage_t<3 * sizeof(void*),
                    alignment_of<void *>::value> __buf;
};
```

pointer to "do-all" function

small buffer + pointer

# Comparison to `std::any`

`ValueWrapper`

```
union {
   std::byte small[smallCapacity];
   void *big;
};
const Methods *methods;
Interface *interface;
```

small buffer + pointer

pointer to function table

pointer to interface

# Comparison to `std::any`

`ValueWrapper`

```
union {
   std::byte small[smallCapacity];
   void *big;
};
const Methods *methods;
Interface *interface;
```

small buffer + pointer

pointer to function table

pointer to interface

# Comparison to `std::any`

`ValueWrapper`

```
union {
  std::byte small[smallCapacity];
  void *big;
};
const Methods *methods;
Interface *interface;
```

small buffer + pointer

pointer to function table

pointer to interface

# Comparison to `std::any`

`ValueWrapper`

```
union {
  std::byte small[smallCapacity];
  void *big;
};
const Methods *methods;
Interface *interface;
```

small buffer + pointer

pointer to function table

pointer to interface

```
auto v = ValueWrapper<Iface>{ Impl{} };
```
```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```
```
Impl::copy ctor
```

```
auto y = std::move(v);
```
```
Impl::copy ctor
```

```
x = y;
```
```
Impl::dtor
Impl::copy ctor
```

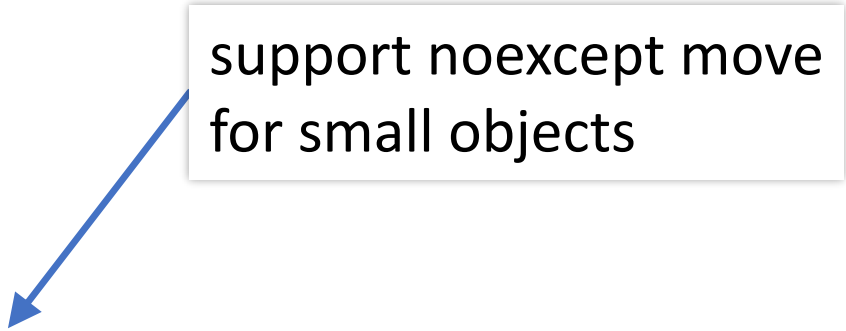
```
x = std::move(y);
```
```
Impl::dtor
Impl::copy ctor
```

```
x->foo();
```
```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

# Let’s move!

```
template<typename T>
static constexpr bool isSmall =
  sizeof(T) <= smallCapacity &&
  alignof(T) <= alignof(void*) &&
  std::is_nothrow_move_constructible_v<T>;

struct Methods {
  void (*destroy)(ValueWrapper &data) noexcept;
  void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
  void (*moveConstruct)(ValueWrapper &dst, ValueWrapper &src) noexcept;
};
```



```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      reinterpret_cast<T*>(&v.small)->~T();
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      dst.interface =
        ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
    },
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveConstruct
      dst.interface =
        ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))};
    }
  };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {//destroy
      delete static_cast<T*>(v.big);
    },
    [](ValueWrapper &dst, const ValueWrapper &src) {//copyConstruct
      auto *instance = new T{ *static_cast<const T*>(src.big) };
      dst.big = instance;
      dst.interface = instance;
    },
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveConstruct
      dst.big = std::exchange(src.big, nullptr);
      dst.interface = std::exchange(src.interface, nullptr);
      src.methods = nullptr;
    }
  };
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
ValueWrapper(ValueWrapper &&other) noexcept : methods{ other.methods } {
  if (methods)
    methods->moveConstruct(*this, other);
}

ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (&other == this)
    return *this;

  if (hasValue())
    methods->destroy(*this);

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
auto v = ValueWrapper<Iface>{ Impl{} };
```
```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```
```
Impl::copy ctor
```

```
auto y = std::move(v);
```
```
Impl::move ctor
```

```
x = y;
```
```
Impl::dtor
Impl::copy ctor
```

```
x = std::move(y);
```
```
Impl::dtor
Impl::move ctor
```

```
x->foo();
```
```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

# Differences to `std::any`

Small object move construction:

```
auto y = std::move(v);
```

| our `ValueWrapper<Iface>` and **MSVC** `std::any` | **libstdc++** and **libc++** `std::any` |
|---|---|
| just moves | moves and destroys the initial object |
| `Impl::move ctor` | `Impl::move ctor`<br>`Impl::dtor` |

# Differences to `std::any`

Small object move assignment:

```
x = std::move(y);
```

| `ValueWrapper<Iface>` and **MSVC** `std::any` | **libstdc++** `std::any` | **libc++** `std::any` |
|---|---|---|
| destroys `this` object and moves | destroys `this` object, moves, and destroys the initial object | destroys `this` object, moves, and destroys the initial object, but in a funny way |
| `Impl::dtor`<br>`Impl::move ctor` | `Impl::dtor`<br>`Impl::move ctor`<br>`Impl::dtor` | `Impl::move ctor`<br>`Impl::dtor`<br>`Impl::move ctor`<br>`Impl::dtor` |

# Differences to `std::any`

Small object move assignment:

```
x = std::move(y);
```

`ValueWrapper<Iface>` and **MSVC** `std::any`


**libstdc++** `std::any`

**libc++** `std::any`

destroys `this` object, moves, and destroys the initial object, but in a funny way

```
Impl::move ctor
Impl::dtor
Impl::move ctor
Impl::dtor
```

# Differences to `std::any`

Small object move assignmer

```
x = std::move(y);
```

`ValueWrapper<Iface>` and **MSVC** `std::any`

destroys `this` object and moves

```
Impl::dtor
Impl::move ctor
```

```
any & operator=(any && __rhs) _NOEXCEPT {
  any(_VSTD::move(__rhs)).swap(*this);
  return *this;
}
```

```
Impl::move ctor
Impl::dtor
Impl::move ctor
Impl::dtor
Impl::move ctor
Impl::dtor
Impl::move ctor
Impl::dtor
Impl::dtor
```

```
Impl::dtor
```

# Differences to `std::any`

Small object copy assignment:

```
x = y;
```

| | `std::any` | |
|---|---|---|
| `ValueWrapper<Iface>` | **MSVC** and **libstdc++** | **libc++** |
| destroys `this` object and copies | constructs a copy, then moves into `this` object | constructs a copy, then moves into `this` object, but in a funny way |
| `Impl::dtor`<br>`Impl::copy ctor` | `Impl::copy ctor`<br>`Impl::dtor`<br>`Impl::move ctor`<br>`Impl::dtor` | `Impl::copy ctor`<br>`Impl::move ctor`<br>`Impl::dtor`<br>`Impl::move ctor`<br>`Impl::dtor` |

# Differences to `std::any`

Small object copy assignment:

```
x = y;
```

needed for
**strong** exception guarantee

| | `std::any` | |
|---|---|---|
| `ValueWrapper<Iface>` | **MSVC** and **libstdc++** | **libc++** |
| destroys `this` object and copies | constructs a copy, then moves into `this` object | constructs a copy, then moves into `this` object, but in a funny way |
| `Impl::dtor`<br>`Impl::copy ctor` | `Impl::copy ctor`<br>`Impl::dtor`<br>`Impl::move ctor`<br>`Impl::dtor` | `Impl::copy ctor`<br>`Impl::move ctor`<br>`Impl::dtor`<br>`Impl::move ctor`<br>`Impl::dtor` |

# Differences to `std::any`

Small object copy assignment:

```
x = y;
```

```
any & operator=(any const & __rhs) {
  any(__rhs).swap(*this);
  return *this;
}
```

| `ValueWrapper<Iface>` | **MSVC** and |
| --- | --- |
| destroys `this` object and copies | constructs moves into |
| `Impl::dtor`<br>`Impl::copy ctor` | `Impl::co`<br>`Impl::dt`<br>`Impl::mo`<br>`Impl::dtor` |

```
Impl::copy ctor
Impl::move ctor
Impl::dtor
Impl::move ctor
Impl::dtor
Impl::move ctor
Impl::dtor
Impl::dtor
```

```
Impl::move ctor
Impl::dtor
```

```
auto v = ValueWrapper<Iface>{ Impl{} };
```
```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```
```
Impl::copy ctor
```

```
auto y = std::move(v);
```
```
Impl::move ctor
```

```
x = y;
```
```
Impl::dtor
Impl::copy ctor
```

```
x = std::move(y);
```
```
Impl::dtor
Impl::move ctor
```

```
x->foo();
```
```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

# Assignment support

```
struct Methods {
  void (*destroy)(ValueWrapper &data) noexcept;
  void (*copyConstruct)(ValueWrapper &dst, const ValueWrapper &src);
  void (*moveConstruct)(ValueWrapper &dst, ValueWrapper &src) noexcept;
  void (*assign)(ValueWrapper &dst, const ValueWrapper &src);
  void (*moveAssign)(ValueWrapper &dst, ValueWrapper &src) noexcept;
};
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
  return {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *reinterpret_cast<T*>(&dst.small) =
          *reinterpret_cast<const T*>(&src.small);
      }
      else {
        reinterpret_cast<T*>(&dst.small)->~T(); // destroy
        dst.interface =
          ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)}; // copy construct
      }
    },
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
      if constexpr (std::is_nothrow_move_assignable_v<T>) {
        *reinterpret_cast<T*>(&dst.small) =
          std::move(*reinterpret_cast<T*>(&src.small));
      }
      else {
        reinterpret_cast<T*>(&dst.small)->~T(); // destroy
        dst.interface =
          ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))}; // move construct
      }
    }
  };
}
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
[](ValueWrapper &dst, const ValueWrapper &src) {//assign
  if constexpr (std::is_copy_assignable_v<T>) {
    *reinterpret_cast<T*>(&dst.small) =
      *reinterpret_cast<const T*>(&src.small);
  }
  else {
    reinterpret_cast<T*>(&dst.small)->~T(); // destroy
    dst.interface =
      // copy construct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
  }
},
    else {
      reinterpret_cast<T*>(&dst.small)->~T(); // destroy
      dst.interface =
        ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))}; // move construct
    }
  }
};
}
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
[](ValueWrapper &dst, const ValueWrapper &src) {//assign
  if constexpr (std::is_copy_assignable_v<T>) {
    *reinterpret_cast<T*>(&dst.small) =
      *reinterpret_cast<const T*>(&src.small);
  }
  else {
    reinterpret_cast<T*>(&dst.small)->~T(); // destroy
    dst.interface =
      // copy construct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
  }
},
    else {
      reinterpret_cast<T*>(&dst.small)->~T(); // destroy
      dst.interface =
        ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))}; // move construct
    }
  }
};
}
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
[](ValueWrapper &dst, const ValueWrapper &src) {//assign
  if constexpr (std::is_copy_assignable_v<T>) {
    *reinterpret_cast<T*>(&dst.small) =
      *reinterpret_cast<const T*>(&src.small);
  }
  else {
    reinterpret_cast<T*>(&dst.small)->~T(); // destroy
    dst.interface =
      // copy construct
      ::new(dst.small) T{*reinterpret_cast<const T*>(&src.small)};
  }
},
    else {
      reinterpret_cast<T*>(&dst.small)->~T(); // destroy
      dst.interface =
        ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))}; // move construct
    }
  }
 };
}
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *reinterpret_cast<T*>(&dst.small) =
```

```
[](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
  if constexpr (std::is_nothrow_move_assignable_v<T>) {
    *reinterpret_cast<T*>(&dst.small) =
      std::move(*reinterpret_cast<T*>(&src.small));
  }
  else {
    reinterpret_cast<T*>(&dst.small)->~T(); // destroy
    dst.interface =
      // move construct
      ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))};
  }
}
```

```
  };
}
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *reinterpret_cast<T*>(&dst.small) =
```

```
[](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
  if constexpr (std::is_nothrow_move_assignable_v<T>) {
    *reinterpret_cast<T*>(&dst.small) =
      std::move(*reinterpret_cast<T*>(&src.small));
  }
  else {
    reinterpret_cast<T*>(&dst.small)->~T(); // destroy
    dst.interface =
      // move construct
      ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))};
  }
}
```

```
  };
}
```

```
template<typename T>
static constexpr Methods getTableForSmallObject() {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *reinterpret_cast<T*>(&dst.small) =
```

```
[](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
  if constexpr (std::is_nothrow_move_assignable_v<T>) {
    *reinterpret_cast<T*>(&dst.small) =
      std::move(*reinterpret_cast<T*>(&src.small));
  }
  else {
    reinterpret_cast<T*>(&dst.small)->~T(); // destroy
    dst.interface =
      // move construct
      ::new (dst.small) T{std::move(*reinterpret_cast<T*>(&src.small))};
  }
}
```

```
  };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
  return {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
      }
      else {
        delete static_cast<T*>(dst.big); // destroy
        auto *instance = new T{ *static_cast<const T*>(src.big) };
        dst.big = instance; // copy construct
        dst.interface = instance;
      }
    },
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
      if constexpr (std::is_nothrow_move_assignable_v<T>) {
        *static_cast<T *>(dst.big) = std::move(*static_cast<T *>(src.big));
      }
      else {
        delete static_cast<T *>(dst.big); // destroy
        dst.big = std::exchange(src.big, nullptr); // move
        dst.interface = std::exchange(src.interface, nullptr);
        src.methods = nullptr;
      }
    }
  };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
[](ValueWrapper &dst, const ValueWrapper &src) {//assign
  if constexpr (std::is_copy_assignable_v<T>) {
    *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
  }
  else {
    delete static_cast<T*>(dst.big); // destroy
    auto *instance = new T{ *static_cast<const T*>(src.big) };
    dst.big = instance; // copy construct
    dst.interface = instance;
  }
},
    }
    else {
      delete static_cast<T *>(dst.big); // destroy
      dst.big = std::exchange(src.big, nullptr); // move
      dst.interface = std::exchange(src.interface, nullptr);
      src.methods = nullptr;
    }
  }
 };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
[](ValueWrapper &dst, const ValueWrapper &src) {//assign
  if constexpr (std::is_copy_assignable_v<T>) {
    *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
  }
  else {
    delete static_cast<T*>(dst.big); // destroy
    auto *instance = new T{ *static_cast<const T*>(src.big) };
    dst.big = instance; // copy construct
    dst.interface = instance;
  }
},
    }
    else {
      delete static_cast<T *>(dst.big); // destroy
      dst.big = std::exchange(src.big, nullptr); // move
      dst.interface = std::exchange(src.interface, nullptr);
      src.methods = nullptr;
    }
  }
 };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
[](ValueWrapper &dst, const ValueWrapper &src) {//assign
  if constexpr (std::is_copy_assignable_v<T>) {
    *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
  }
  else {
    delete static_cast<T*>(dst.big); // destroy
    auto *instance = new T{ *static_cast<const T*>(src.big) };
    dst.big = instance; // copy construct
    dst.interface = instance;
  }
},
    }
    else {
      delete static_cast<T *>(dst.big); // destroy
      dst.big = std::exchange(src.big, nullptr); // move
      dst.interface = std::exchange(src.interface, nullptr);
      src.methods = nullptr;
    }
  }
 };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
      }
      else {
```

```
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
      if constexpr (std::is_nothrow_move_assignable_v<T>) {
        *static_cast<T *>(dst.big) = std::move(*static_cast<T *>(src.big));
      }
      else {
        delete static_cast<T *>(dst.big); // destroy
        dst.big = std::exchange(src.big, nullptr); // move
        dst.interface = std::exchange(src.interface, nullptr);
        src.methods = nullptr;
      }
    }
```

```
  };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
      }
      else {
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
      if constexpr (std::is_nothrow_move_assignable_v<T>) {
        *static_cast<T *>(dst.big) = std::move(*static_cast<T *>(src.big));
      }
      else {
        delete static_cast<T *>(dst.big); // destroy
        dst.big = std::exchange(src.big, nullptr); // move
        dst.interface = std::exchange(src.interface, nullptr);
        src.methods = nullptr;
      }
    }
  };
}
```

```
template<typename T>
static constexpr Methods getTableForBigObject() {
    [](ValueWrapper &v) noexcept {/*destroy ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {/*copyConstruct ...*/},
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {/*moveConstruct ...*/},
    [](ValueWrapper &dst, const ValueWrapper &src) {//assign
      if constexpr (std::is_copy_assignable_v<T>) {
        *static_cast<T*>(dst.big) = *static_cast<const T*>(src.big);
      }
      else {
    [](ValueWrapper &dst, ValueWrapper &src) noexcept {//moveAssign
      if constexpr (std::is_nothrow_move_assignable_v<T>) {
        *static_cast<T *>(dst.big) = std::move(*static_cast<T *>(src.big));
      }
      else {
        delete static_cast<T *>(dst.big); // destroy
        dst.big = std::exchange(src.big, nullptr); // move
        dst.interface = std::exchange(src.interface, nullptr);
        src.methods = nullptr;
      }
    }
  };
}
```

# Assignment support

```
ValueWrapper &operator=(const ValueWrapper &other) {
  if (hasValue()) {
    if (methods == other.methods) {
      methods->assign(*this, other);
      return *this;
    }
    methods->destroy(*this);
    methods = nullptr;
  }

  if (other.methods) {
    other.methods->copyConstruct(*this, other);
    methods = other.methods;
  }
  return *this;
}
```

# Assignment support

```
ValueWrapper &operator=(ValueWrapper &&other) noexcept {
  if (hasValue()) {
    if (methods == other.methods) {
      methods->moveAssign(*this, other);
      return *this;
    }

    methods->destroy(*this);
  }

  methods = other.methods;
  if (methods)
    methods->moveConstruct(*this, other);

  return *this;
}
```

```
auto v = ValueWrapper<Iface>{ Impl{} };
```

```
Impl::ctor
Impl::move ctor
Impl::dtor
```

```
auto x = v;
```

```
Impl::copy ctor
```

```
auto y = std::move(v);
```

```
Impl::move ctor
```

```
x = y;
```

```
Impl::copy =
```

```
x = std::move(y);
```

```
Impl::move =
```

```
x->foo();
```

```
Impl::foo(): abc
```

```
Impl::dtor
Impl::dtor
Impl::dtor
```

# Other features

- emplace
- value assignment

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T, typename... Args>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
std::decay_t<T> &emplace(Args&&...args) {
  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  T *instance = nullptr;
  if constexpr (isSmall<std::decay_t<T>>) {
    instance = ::new(small) std::decay_t<T>{ std::forward<Args>(args)... };
  }
  else {
    instance = new std::decay_t<T>{ std::forward<Args>(args)... };
    big = instance;
  }
  methods = &table<std::decay_t<T>>;
  interface = instance;
  return *instance;
}
```

```
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
    if (methods == &table<std::decay_t<T>>) {
      if constexpr (isSmall<std::decay_t<T>>) {
        *reinterpret_cast<T*>(&small) = std::forward<T>(object);
      }
      else {
        *static_cast<T*>(big) = std::forward<T>(object);
      }
      return *this;
    }
  }

  if (hasValue()) {
    methods->destroy(*this);
    methods = nullptr;
  }

  construct(std::forward<T>(object));
  methods = &table<std::decay_t<T>>;

  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
  if (methods == &table<std::decay_t<T>>) {
    if constexpr (isSmall<std::decay_t<T>>) {
      *reinterpret_cast<T*>(&small) = std::forward<T>(object);
    }
    else {
      *static_cast<T*>(big) = std::forward<T>(object);
    }
    return *this;
  }
}
  construct(std::forward<T>(object));
  methods = &table<std::decay_t<T>>;

  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
  if (methods == &table<std::decay_t<T>>) {
    if constexpr (isSmall<std::decay_t<T>>) {
      *reinterpret_cast<T*>(&small) = std::forward<T>(object);
    }
    else {
      *static_cast<T*>(big) = std::forward<T>(object);
    }
    return *this;
  }
}
  construct(std::forward<T>(object));
  methods = &table<std::decay_t<T>>;

  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
  if (methods == &table<std::decay_t<T>>) {
    if constexpr (isSmall<std::decay_t<T>>) {
      *reinterpret_cast<T*>(&small) = std::forward<T>(object);
    }
    else {
      *static_cast<T*>(big) = std::forward<T>(object);
    }
    return *this;
  }
}
  construct(std::forward<T>(object));
  methods = &table<std::decay_t<T>>;

  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
    if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
      if (methods == &table<std::decay_t<T>>) {
        if constexpr (isSmall<std::decay_t<T>>) {
          *reinterpret_cast<T*>(&small) = std::forward<T>(object);
        }
        else {
          *static_cast<T*>(big) = std::forward<T>(object);
        }
        return *this;
      }
    }
  construct(std::forward<T>(object));
  methods = &table<std::decay_t<T>>;

  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
    if (methods == &table<std::decay_t<T>>) {
      if constexpr (isSmall<std::decay_t<T>>) {
        *reinterpret_cast<T*>(&small) = std::forward<T>(object);
      }
      else {
if (hasValue()) {
  methods->destroy(*this);
  methods = nullptr;
}

construct(std::forward<T>(object));
methods = &table<std::decay_t<T>>;

return *this;
  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
    if (methods == &table<std::decay_t<T>>) {
      if constexpr (isSmall<std::decay_t<T>>) {
        *reinterpret_cast<T*>(&small) = std::forward<T>(object);
      }
      else {
```

```
if (hasValue()) {
  methods->destroy(*this);
  methods = nullptr;
}

construct(std::forward<T>(object));
methods = &table<std::decay_t<T>>;

return *this;
```

```
  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
    if (methods == &table<std::decay_t<T>>) {
      if constexpr (isSmall<std::decay_t<T>>) {
        *reinterpret_cast<T*>(&small) = std::forward<T>(object);
      }
      else {
if (hasValue()) {
  methods->destroy(*this);
  methods = nullptr;
}

construct(std::forward<T>(object));
methods = &table<std::decay_t<T>>;

return *this;
  return *this;
}
```

```
template<typename T>
ValueWrapper &operator=(T &&object) {
  if constexpr (std::is_assignable_v<std::decay_t<T>, T&&>) {
    if (methods == &table<std::decay_t<T>>) {
      if constexpr (isSmall<std::decay_t<T>>) {
        *reinterpret_cast<T*>(&small) = std::forward<T>(object);
      }
      else {
if (hasValue()) {
  methods->destroy(*this);
  methods = nullptr;
}

construct(std::forward<T>(object));
methods = &table<std::decay_t<T>>;

return *this;
  return *this;
}
```

# Value assignment

```
private:
  //...
  template<typename T>
  void construct(T &&object) {
    if constexpr (isSmall<std::decay_t<T>>) {
      interface =
        ::new(small) std::decay_t<T>{ std::forward<T>(object) };
    }
    else {
      auto *instance = new std::decay_t<T>{ std::forward<T>(object) };
      big = instance;
      interface = instance;
    }
  }
```

# Refactored constructor

```
template<typename T>
  requires (std::is_base_of_v<Interface, std::decay_t<T>>)
explicit ValueWrapper(T &&object) :
  methods{ &table<std::decay_t<T>> }
{
  construct(std::forward<T>(object));
}
```

# What else?

- enforce everywhere that the value type must be copy-constructible
  - to be modeled after interface of `std::any`
  - add to all functions where value type is concerned:

```
requires (std::is_copy_constructible_v<std::decay_t<T>>)
```

- in-place construction?
- reset?

```
x = {};
```

- swap?
- experiment with function tables vs. "do-all" functions?
  - performance?
  - binary size?

# What else?

- enforce everywhere that the value type must be copy-constructible
  - to be modeled after interface of `std::any`
  - add to all functions where value type is concerned:

```
requires (std::is_copy_constructible_v<std::decay_t<T>>)
```

- in-place construction?
- reset?

```
x = {};
```

- swap?
- experiment with function tables vs. "do-all" functions?
  - performance?
  - binary size?

# What else?

- enforce everywhere that the value type must be copy-constructible
  - to be modeled after interface of `std::any`
  - add to all functions where value type is concerned:

```
requires (std::is_copy_constructible_v<std::decay_t<T>>)
```

- in-place construction?
- reset?

```
x = {};
```

- swap?
- experiment with function tables vs. "do-all" functions?
  - performance?
  - binary size?

# What else?

- enforce everywhere that the value type must be copy-constructible
  - to be modeled after interface of `std::any`
  - add to all functions where value type is concerned:

```
requires (std::is_copy_constructible_v<std::decay_t<T>>)
```

- in-place construction?
- reset?

```
x = {};
```

- swap?
- experiment with function tables vs. "do-all" functions?
  - performance?
  - binary size?

# What else?

- enforce everywhere that the value type must be copy-constructible
  - to be modeled after interface of `std::any`
  - add to all functions where value type is concerned:

```
requires (std::is_copy_constructible_v<std::decay_t<T>>)
```

- in-place construction?
- reset?

```
x = {};
```

- swap?
- experiment with function tables vs. "do-all" functions?
  - performance?
  - binary size?

# Thanks for listening!

# Fun with type erasure: implementing a value wrapper for polymorphic types

Pavel Novikov

@cpp_ape

R&D Align Technology


Thanks to Arthur O'Dwyer for feedback!

Slides: https://git.io/JcTV1