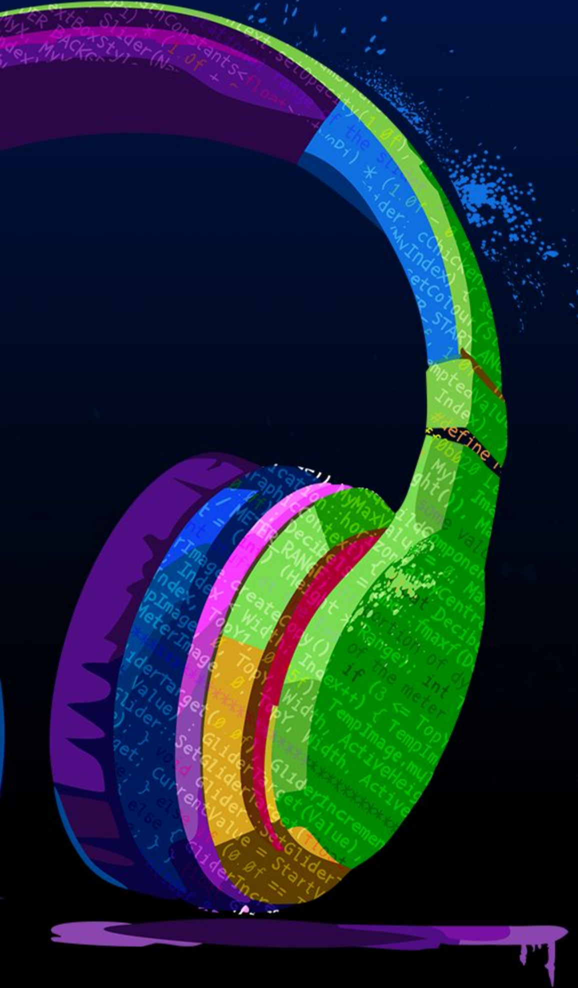


ADC24 Bristol

BUG-FREE JUCE UI

STRUCTURE YOUR GUI CODE FOR STABILITY, TESTABILITY & CLEAN ARCHITECTURE

JAN WILCZEK

What is this talk about?

- Make your JUCE UI bug-free
- Applies to app and plugin UIs
- A way to think about JUCE GUI architecture in general

Slides:
https://github.com/JanWilczek/adc24-talk

Who is this talk for?

- Mid & senior devs working in JUCE
- Juniors with JUCE experience
- C++ developers who write GUIs

Who am I?

- Jan Wilczek
- Audio Programming Consultant & Educator
- Author of TheWolfSound.com blog & YouTube channel
  - youtube.com/@WolfSoundAudio
- Author of the DSP Pro online course on learning Digital Signal Processing from scratch (no maths, no programming background)
  - wolfsoundacademy.com/dsp-pro
- ADC Mentor

Why this talk?

- Teaching JUCE & C++ experience
- Consulting experience: this year’s moderately-sized app project in JUCE
    - lack of high-quality reference GUI code
- Dev experience: Developing my own synth live

Definitions

Model: code representation of the domain.

- interacts with the outside world via *ports* (abstract interfaces) implemented with *adapters* (GUI, console commands, web requests, etc.)
- consists of *entities* and *use cases*

View: code responsible for displaying content to the user.

- e.g., subclasses of `juce::Component`

Component: `juce::Component`

Fake: unit test-only piece of code mimicking dependencies

- e.g., fake database, fake file, fake HTTP client etc.
- should be fast, ideally just return a value

Definitions

UI state: state of the UI at a given time

- Completely captures how the UI should look and behave

UI logic: code that controls the UI state (UI appearance and behavior)

- e.g., component positioning, button click handling, etc.

Problem 1

How to make sure your GUI works as expected?

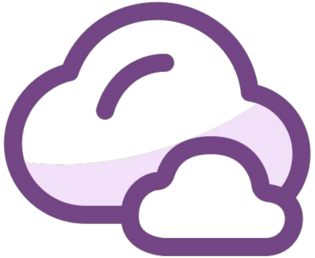
Common GUI interactions

- interactions that change the Model, that are driven by the domain
  - e.g., preset selected
- interactions that change the GUI
  - e.g., theme switched from light to dark
- generic interactions
  - e.g., app opened, app closed
- updates from the Model
- updates from the runtime environment
  - e.g., screen resolution changed

Is my GUI code correct?

- Is a correct value displayed?
- What if an error occurs?
- Is every possible interaction covered and meaningful?
- What happens when the app is resized?


THIS IS FINE.



How can I ensure the GUI code works correctly?

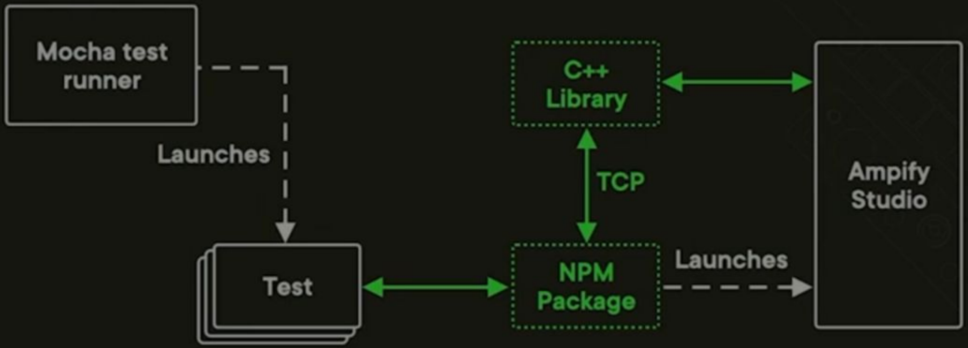
ⓘ Click **Present with Slido** or install our [Chrome extension] to activate this poll while presenting.

How can I ensure the GUI code works correctly?

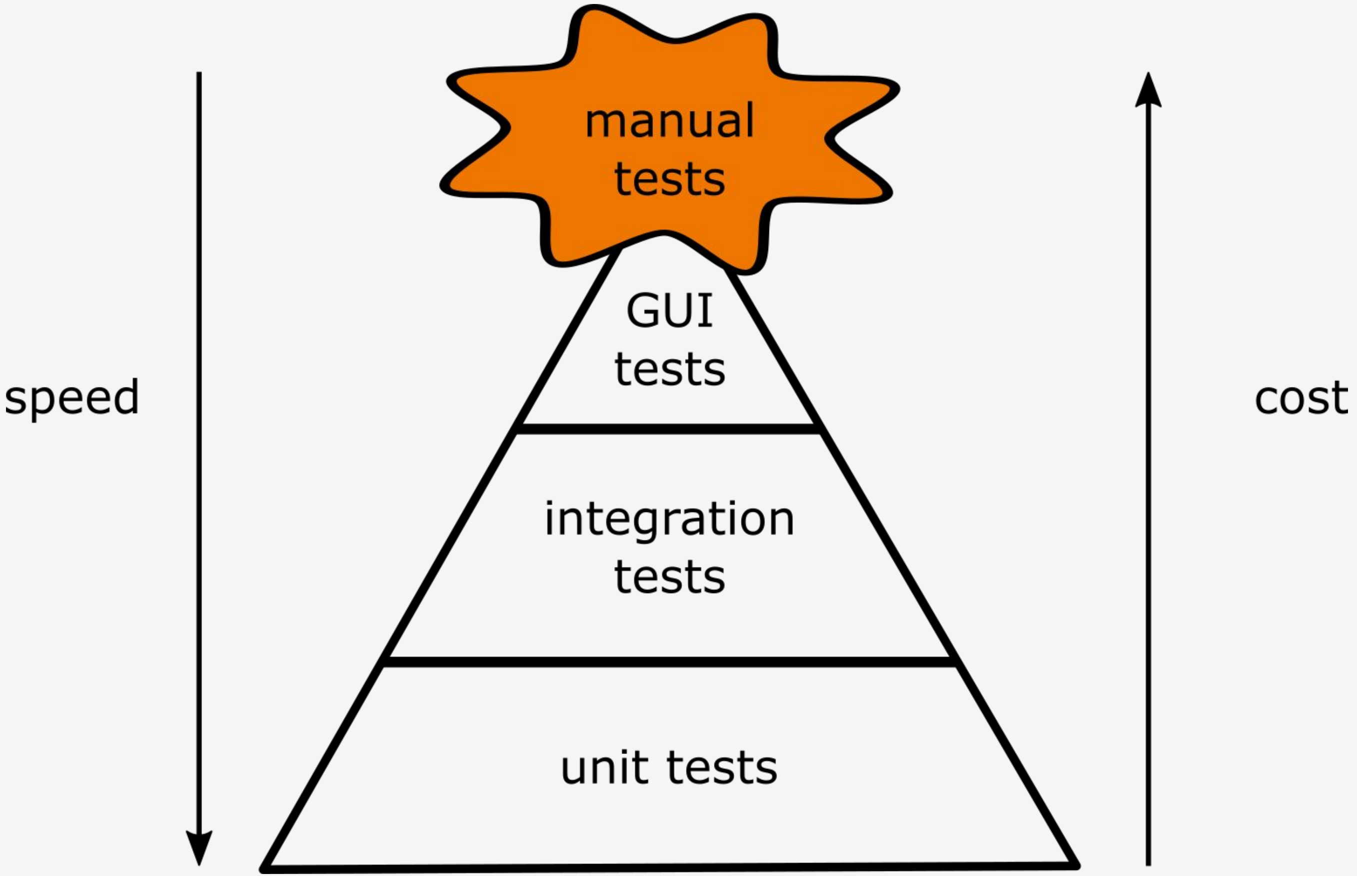
- Edit and Pray (~Michael Feathers)
- Manual tests
- QA testing
- End-2-end GUI tests that somehow mimic user UI actions (click, key press, etc.)

```csharp
[TestMethod]
public void TestDoSomething()
{
    // given
    var app = Application.Launch("MyApp.exe");
    var window = app.GetWindow("My App Window Title", InitializeOption.NoCache);
    var btnMyButton = window.Get<Button>("btnMyButtonName");

    // when
    btnMyButton.Click();

    // then
    var txtMyTextBox = window.Get<TextBox>("txtMyTextBox");
    Assert.IsTrue(txtMyTextBox.Text == "my expected result");

    // cleanup
    app.Close();
}
```

Our Solution



Joe Noël


manual tests
GUI tests
integration tests
unit tests
speed
cost

Is there a better solution?

- fast
- standard C++
- no specialized testing framework
- assert all desired effects
- easy CI/CD integration

Problem 2

How to write automated GUI tests?

WebView UIs (JUCE 8)

- Established end-2-end testing frameworks for
  - DOM interaction
  - backend REST calls
  - triggering JavaScript events
- What about "traditional" JUCE Components?

3 testability obstacles

Typical JUCE Component

```
class CustomComponent : public juce::Component {
public:
  CustomComponent() {
    button_.onClick = [] {
      // do stuff
    };
  }

private:
  juce::TextButton button_{"Click me!"};
};
```

Testability Obstacle 1

```
class CustomComponent : public juce::Component {
public:
  CustomComponent() {
    button_.onClick = [] {
      // do stuff
    };
  }

private:
  juce::TextButton button_{"Click me!"};
};
```

we cannot call this callback in unit test*

```cpp
class CustomComponent : public juce::Component {
public:
  CustomComponent(juce::ValueTree model) : model_{model} {
    button_.onClick = [this] {
      if (auto child = model_.getChildWithProperty("NESTING", nesting); child.isValid()) {
        nesting++;
        child.addChild(juce::ValueTree{"CHILD", {{ "NESTING", nesting}}, {}}, nullptr);
      }
    };
  }

private:
  juce::TextButton button_{"Click me!"};
  juce::ValueTree model_;
  int nesting = 0;
};
```

```cpp
class CustomComponent : public juce::Component {
public:
  CustomComponent(juce::ValueTree model) : model_{model} {
    button_.onClick = [this] {
      if (auto child = model_.getChildWithProperty("NESTING", nesting); child.isValid()) {
        nesting++;
        child.addChild(juce::ValueTree{"CHILD", {{ "NESTING", nesting}}, {}}, nullptr);
      }
    };
  }

private:
  juce::TextButton button_{"Click me!"};
  juce::ValueTree model_;
  int nesting = 0;
};
```

Model manipulation in the View

```cpp
class CustomComponent : public juce::Component,
                        private juce::ValueTree::Listener {
public:
  CustomComponent(juce::ValueTree model) : model_{model} {
    model_.addListener(this);
  }

private:
  void valueTreePropertyChanged(juce::ValueTree& treeWhosePropertyHasChanged,
                                const juce::Identifier &property) {
    if (treeWhosePropertyHasChanged == model_ && property == "BUTTON_TEXT") {
      button_.setButtonText(treeWhosePropertyHasChanged.getProperty("BUTTON_TEXT"));
    }
  }

  juce::TextButton button_{"Click me!"};
  juce::ValueTree model_;
};
```

```cpp
class CustomComponent : public juce::Component,
                        private juce::ValueTree::Listener {
public:
  CustomComponent(juce::ValueTree model) : model_{model} {
    model_.addListener(this);
  }

private:
  void valueTreePropertyChanged(juce::ValueTree& treeWhosePropertyHasChanged,
                                const juce::Identifier &property) {
    if (treeWhosePropertyHasChanged == model_ && property == "BUTTON_TEXT") {
      button_.setButtonText(treeWhosePropertyHasChanged.getProperty("BUTTON_TEXT"));
    }
  }

  juce::TextButton button_{"Click me!"};
  juce::ValueTree model_;
};
```

dependence on the Model in the View

cannot assert it

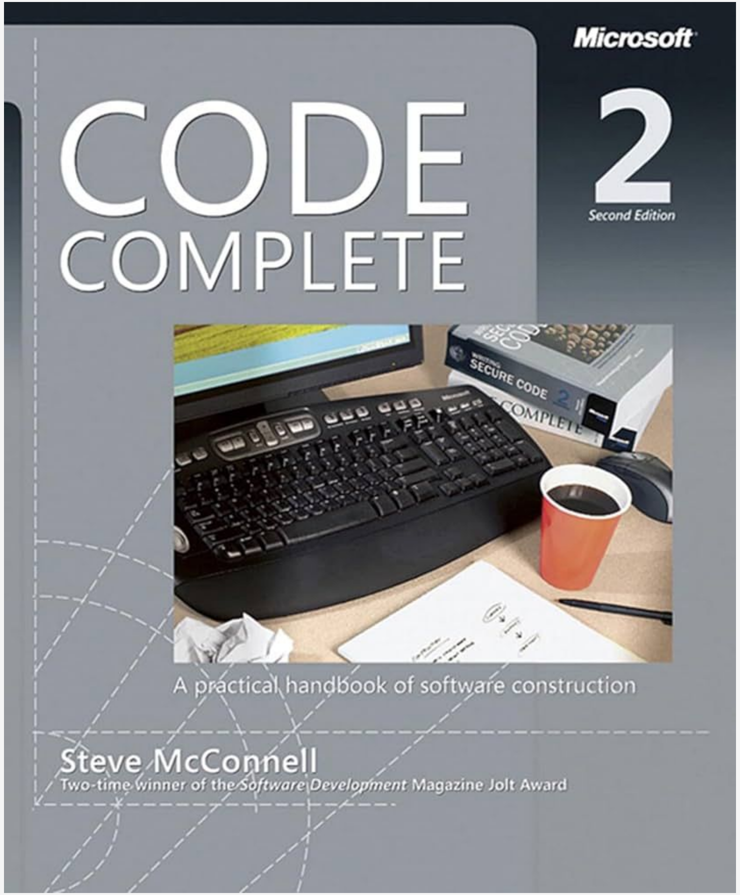
Typical JUCE Component's responsibilities

- holds UI widgets
- holds UI state
- positions the widgets
- paints additional stuff
- handles user actions
- manipulates the Model
- observes for changes to the Model
- manipulates other Components
- …it simply does too much!

*"Program **into** your language,*

not in it."

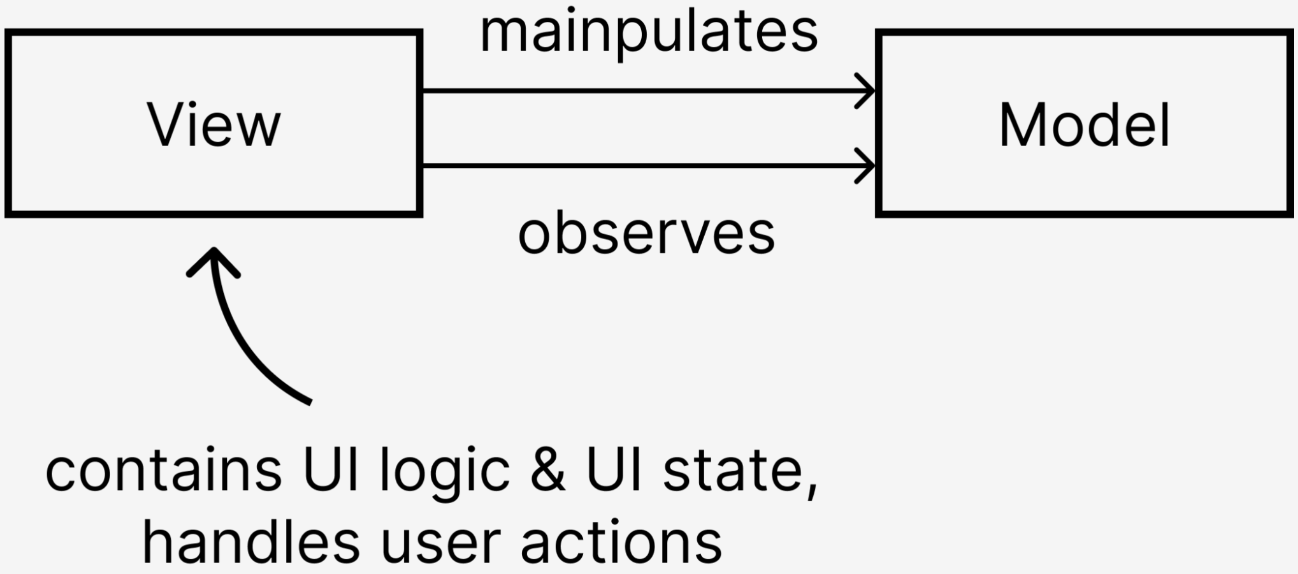
Steve McConnell
Code Complete, 2nd edition



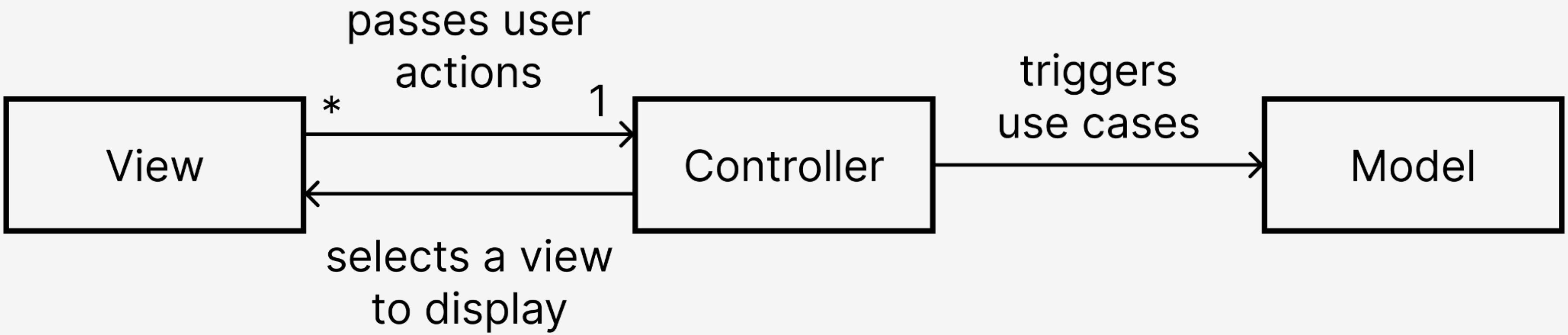
Model-View-ViewModel (MVVM) pattern

A tour of GUI architectures

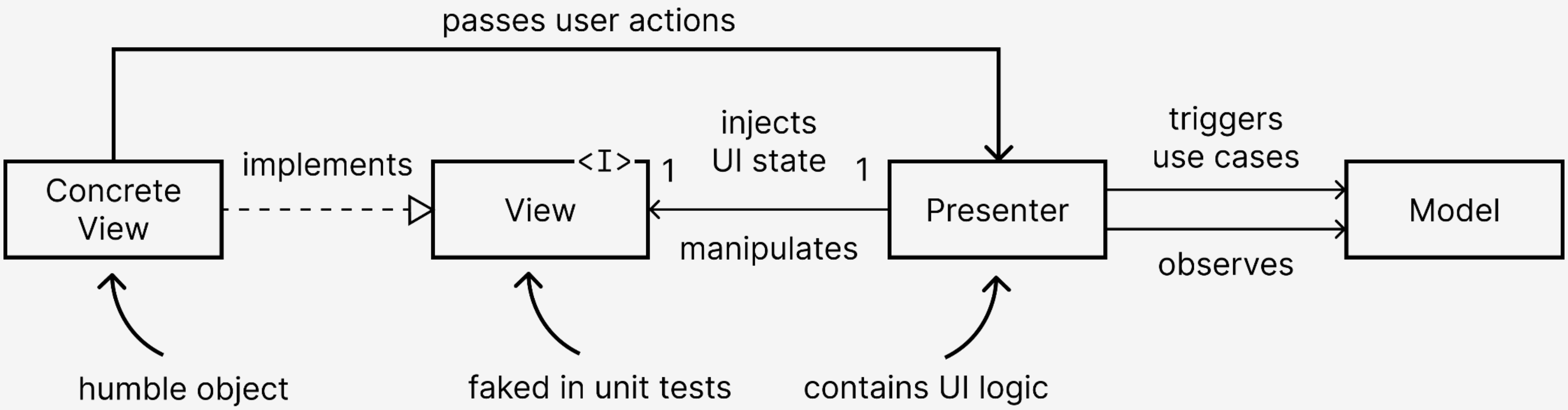
"Put It All In The Component" (PITA)



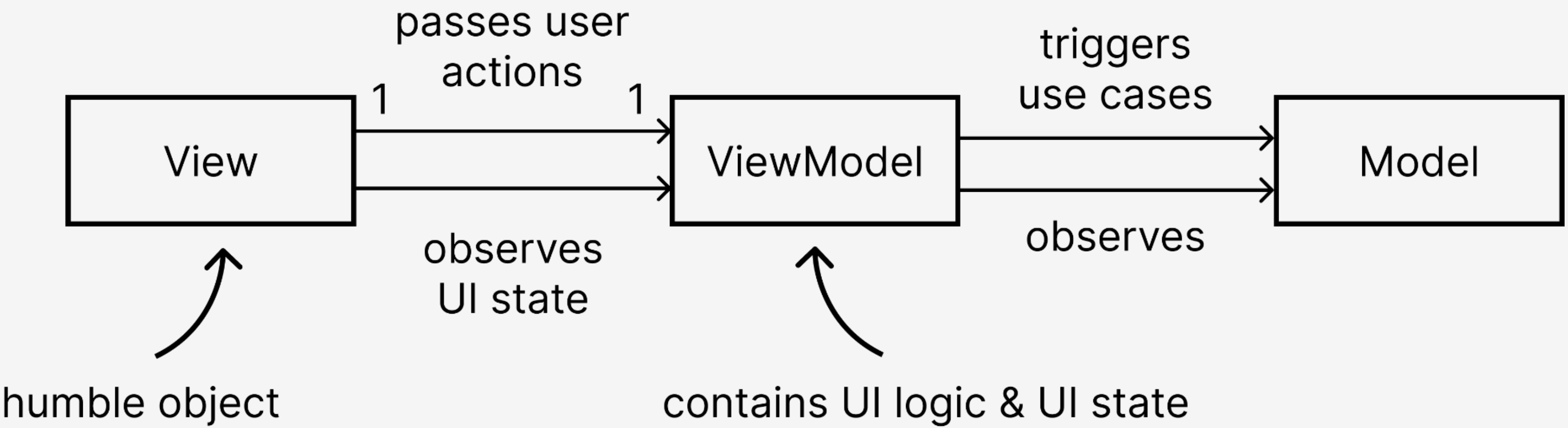
Model-View-Controller (MVC)



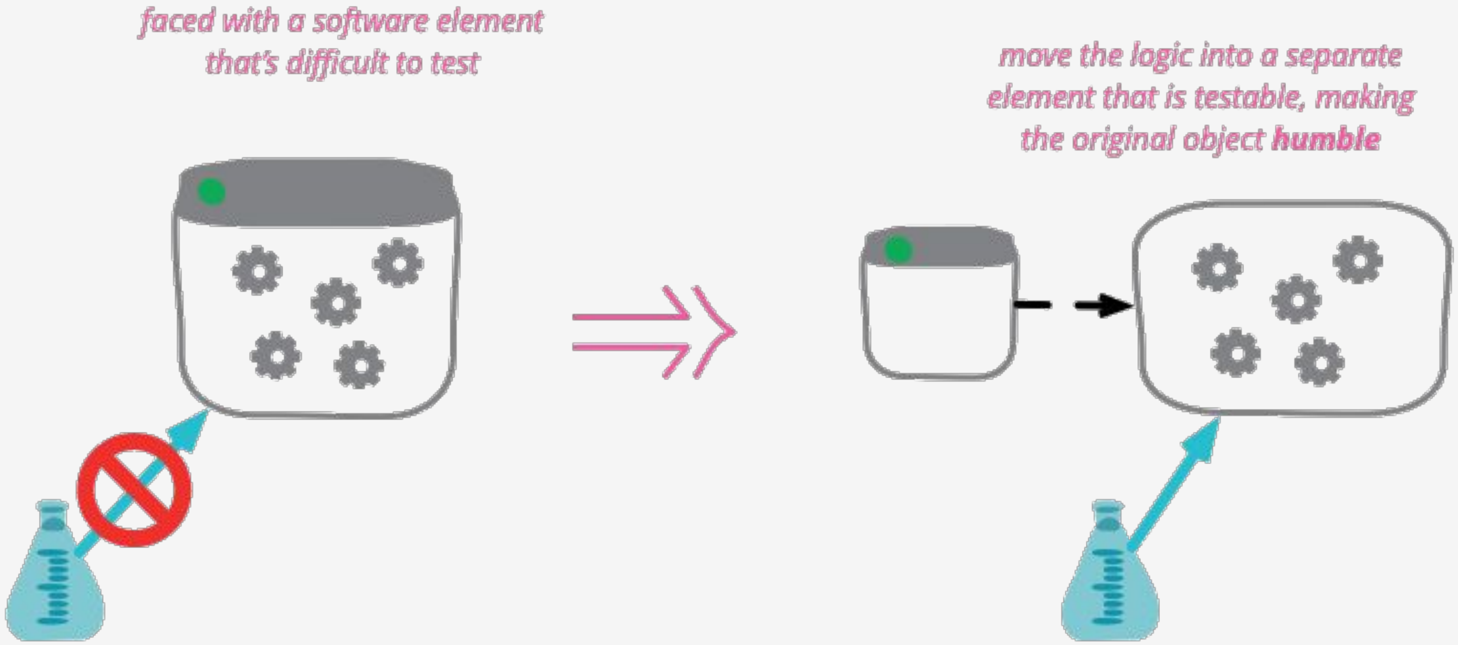
Model-View-Presenter (MVP) / Passive View



Model-View-ViewModel (MVVM) / Presentation Model



Humble object (~Michael Feathers)



https://martinfowler.com/bliki/HumbleObject.html

```kotlin
class MainActivity : ComponentActivity() {
  @Composable
  private fun PlayControl(modifier: Modifier, synthesizerViewModel: WavetableSynthesizerViewModel) {
    val playButtonLabel = synthesizerViewModel.playButtonLabel.observeAsState()

    PlayControlContent(modifier = modifier,
      onClick = {
        synthesizerViewModel.playClicked()
      },
      buttonLabel = stringResource(playButtonLabel.value!!))
  }

  @Composable
  private fun PlayControlContent(modifier: Modifier, onClick: () -> Unit, buttonLabel: String) {
    Button(modifier = modifier,
      onClick = onClick) {
      Text(buttonLabel)
    }
  }
}
```

```kotlin
class WavetableSynthesizerViewModel : ViewModel() {
  var wavetableSynthesizer: WavetableSynthesizer? = //...

  private val _playButtonLabel = MutableLiveData(R.string.play)
  val playButtonLabel: LiveData<Int>
    get() {
      return _playButtonLabel
    }
}
```

```kotlin
class WavetableSynthesizerViewModel : ViewModel() {
  fun playClicked() {
    viewModelScope.launch {
      if (wavetableSynthesizer?.isPlaying() == true) {
        wavetableSynthesizer?.stop()
      } else {
        wavetableSynthesizer?.play()
      }
      updatePlayButtonLabel()
    }
  }

  private fun updatePlayButtonLabel() {
    viewModelScope.launch {
      if (wavetableSynthesizer?.isPlaying() == true) {
        _playButtonLabel.value = R.string.stop
      } else {
        _playButtonLabel.value = R.string.play
      }
    }
  }
}
```

Solution: bug-free JUCE UI

Q: How to make your UI code bug-free?

A: Unit test it.

Q: How to test `juce::Component` subclasses?

A: You can't without breaking the invariants or a lot of boilerplate code.

Q: How to test the UI logic then?

1. Separate the UI logic and state to a ViewModel.
2. Make the `juce::Component` subclass a humble object.
3. Unit test the ViewModel.

Problem 3

How to use MVVM in C++ (JUCE)?

All You Need Is Data Binding

- Observer pattern
- Event-Subscriber
- Event-Listener
- Observer-Listener
- Publisher-Subscriber
- Callback
- Signals and Slots
- Events & Event Handlers

Data binding in WinUI (XAML)

```xml
<Window x:Class="Quickstart.MainWindow" ...>
  <Grid>
    <TextBlock Text="{x:Bind ViewModel.TextBlockContent}"
               HorizontalAlignment="Center"
               VerticalAlignment="Center"/>
  </Grid>
</Window>
```

`juce::CachedValue<T>` is not an option

*This class acts as a typed wrapper around a **property inside a ValueTree**.*

- Does not allow observing
- Exposes too much from the Model

`juce::Value` is not an option

Contains a reference to a var object, and can get and set its value. Listeners can be attached to be told when the value is changed.

- Allows observing but…

- Is dynamically typed
- Is weakly typed
- Observing is unhandy (via the `Listener` interface)

```cpp
using ScopedConnection = boost::signals2::scoped_connection;
template <typename T>
class ObservableProperty {
public:
 using SignalType = boost::signals2::signal<void(const T&)>;
 [[nodiscard]] ScopedConnection observe(const typename SignalType::slot_type& onChangedCallback) {
   return onChanged_.connect(onChangedCallback);
 }
 [[nodiscard]] const T& value() const noexcept { return value_; }
protected:
 explicit ObservableProperty(const T& initialValue) : value_{initialValue} {}
 void setValueAndNotify(const T& newValue) {
   value_ = newValue;
   onChanged_(this->value_);
 }
private:
 T value_;
 SignalType onChanged_;
};
```

```cpp
using ScopedConnection = boost::signals2::scoped_connection;
template <typename T>
class ObservableProperty {
public:
 using SignalType = boost::signals2::signal<void(const T&)>;
 [[nodiscard]] ScopedConnection observe(const typename SignalType::slot_type& onChangedCallback) {
   return onChanged_.connect(onChangedCallback);
 }
 [[nodiscard]] const T& value() const noexcept { return value_; }
protected:
 explicit ObservableProperty(const T& initialValue) : value_{initialValue} {}
 void setValueAndNotify(const T& newValue) {
   value_ = newValue;
   onChanged_(this->value_);
 }
private:
 T value_;
 SignalType onChanged_;
};
```

```cpp
template <typename T>
class MutableObservableProperty : public ObservableProperty<T> {
public:
 explicit MutableObservableProperty(const T& initialValue = {})
     : ObservableProperty<T>(initialValue) {}

 void setValue(const T& newValue) {
   if (newValue != this->value()) {
     setValueForced(newValue);
   }
 }

 void setValueForced(const T& newValue) { this->setValueAndNotify(newValue); }
};
```

```cpp
// Calls f on the message (main, GUI) thread if is available. Otherwise, calls f directly.
void callOnMessageThreadIfNotNull(std::function<void()> f);

template <typename T>
class LiveObservableProperty : public MutableObservableProperty<T> {
public:
  explicit LiveObservableProperty(const T& initialValue = {})
      : MutableObservableProperty<T>(initialValue) {}

  void postValue(const T& newValue) {
    callOnMessageThreadIfNotNull(
        [this, newValue] { this->setValue(newValue); });
  }

  void postValueForced(const T& newValue) {
    callOnMessageThreadIfNotNull(
        [this, newValue] { this->setValueForced(newValue); });
  }
};
```

```cpp
// Calls f on the message (main, GUI) thread if is available. Otherwise, calls f directly.
void callOnMessageThreadIfNotNull(std::function<void()> f);

template <typename T>
class LiveObservableProperty : public MutableObservableProperty<T> {
public:
  explicit LiveObservableProperty(const T& initialValue = {})
      : MutableObservableProperty<T>(initialValue) {}

  void postValue(const T& newValue) {
    callOnMessageThreadIfNotNull(
        [this, newValue] { this->setValue(newValue); });
  }

  void postValueForced(const T& newValue) {
    callOnMessageThreadIfNotNull(
        [this, newValue] { this->setValueForced(newValue); });
  }
};
```

```cpp
class Holder {
public:
  [[nodiscard]] ObservableProperty<int>& property() noexcept {
    return property_;
  }

  void incrementValue() { property_.setValue(property_.value() + 1); }

private:
  MutableObservableProperty<int> property_{0};
} holder;

const auto connection = holder.property().observe([&](const int& value) {
  // callback code
});

// holder.property().setValue(1);   // Doesn't work although property() is public.
holder.incrementValue();   // Tightly restricted API
```

```cpp
class Holder {
public:
  Holder() : property_{0} {}

  OBSERVABLE_PROPERTY(property, int)

  void incrementValue() { property_.setValue(property_.value() + 1); }
} holder;

const auto connection = holder.property().observe([&](const int& value) {
  // callback code
});

// holder.property().setValue(1);   // Doesn't work although property() is public.
holder.incrementValue();   // Tightly restricted API
```

observable-property

https://github.com/JanWilczek/observable-property

- C++, header-only
- contains boost-signals2
- Boost license
  (even more permissive than MIT)
- supports CMake workflow
- suggestions and PRs welcome!

Example of MVVM in a JUCE app

Plotting a filter's magnitude response

```cpp
class EqFilterViewModel {
public:
 using CutoffFrequencyChangedUseCase =
   std::function<void(double newCutoffFrequencyHz)>;

 LIVE_OBSERVABLE_PROPERTY(frequencySliderValue, double)

 explicit EqFilterViewModel(
     CutoffFrequencyChangedUseCase onCutoffFrequencyChanged)
     : frequencySliderValue_{100.},
       cutoffFrequencyChanged_{std::move(onCutoffFrequencyChanged)} {}

 void onCutoffFrequencyChanged(double newValue) {
    cutoffFrequencyChanged_(newValue);
 }

private:
 CutoffFrequencyChangedUseCase cutoffFrequencyChanged_;
};
```

```cpp
class EqFilterComponent : public juce::Component {
public:
   // ...
private:
 std::unique_ptr<EqFilterViewModel> viewModel_;
 std::vector<ScopedConnection> connections_;
 juce::Slider frequencySlider_;
};
```

```cpp
explicit EqFilterComponent(std::unique_ptr<EqFilterViewModel> viewModel)
    : viewModel_{std::move(viewModel)} {
  // ... (slider range, style setup, addAndMakeVisible(), etc.) ...
  frequencySlider_.setValue(viewModel_->frequencySliderValue().value(),
                            juce::dontSendNotification);
  frequencySlider_.onValueChange = [this] {
    viewModel_->onCutoffFrequencyChanged(frequencySlider_.getValue());
  };
  connections_.push_back(
      viewModel_->frequencySliderValue().observe([this](double newValue) {
        frequencySlider_.setValue(newValue, juce::dontSendNotification);
      }));
}
```

```
class EqFilter {
public:
 OBSERVABLE_PROPERTY(magnitudeResponse, dsp::MagnitudeResponse)

 void onCutoffFrequencyChanged(double newCutoffFrequency) {
   cutoffFrequency_ = newCutoffFrequency;
   magnitudeResponse_.setValueForced(calculateMagnitudeResponse());
 }
private:
 [[nodiscard]] dsp::MagnitudeResponse calculateMagnitudeResponse() const {
   /* magnitude response calculations */ return result;
 }

 double cutoffFrequency_{100.};
};
```

```cpp
class MagnitudeResponsePlotViewModel {
public:
  explicit MagnitudeResponsePlotViewModel(
     ObservableProperty<dsp::MagnitudeResponse>& magnitudeResponse)
     : magnitudeResponse_(magnitudeResponse.value()) {
   connections_.push_back(
       magnitudeResponse.observe([this](const auto& newResponse) {
         magnitudeResponse_ = newResponse;
         updatePlot(); }));
 }
 void onPlotBoundsChanged(const juce::Rectangle<int>& newBounds) {
   plotBounds_ = newBounds;
   updatePlot();
 } // ...
```

```cpp
class MagnitudeResponsePlotViewModel {
public:
  // ...
  LIVE_OBSERVABLE_PROPERTY(plot, juce::Path)
private:
 void updatePlot() { plot_.postValueForced(calculateMagnitudeResponsePlot()); }

 [[nodiscard]] juce::Path calculateMagnitudeResponsePlot() const {
   /* calculations involving magnitudeResponse_ and plotBounds_ */ return result;
 }
 juce::Rectangle<int> plotBounds_;
 dsp::MagnitudeResponse magnitudeResponse_;
 std::vector<ScopedConnection> connections_;
};
```

```cpp
class PlotComponent : public juce::Component {
public:
  // ...
private:
 void drawPlot(juce::Graphics& g) {
   g.setColour(juce::Colours::white);
   g.setOpacity(1.f);
   g.strokePath(plotViewModel_->plot().value(), juce::PathStrokeType{5.f});
 }

 std::unique_ptr<MagnitudeResponsePlotViewModel> plotViewModel_;
 std::vector<ScopedConnection> connections_;
};
```

```cpp
explicit PlotComponent(
    std::unique_ptr<MagnitudeResponsePlotViewModel> plotViewModel)
    : plotViewModel_{std::move(plotViewModel)} {
  connections_.push_back(plotViewModel_->plot().observe(
      [this](const juce::Path&) { repaint(); }));
}

void paint(juce::Graphics& g) override { drawPlot(g); }

void resized() override {
  plotViewModel_->onPlotBoundsChanged(getLocalBounds());
}
```

Wiring

```
EqFilter model;

EqFilterComponent eqFilterComponent{
    std::make_unique<EqFilterViewModel>([&](double newCutoffFrequencyHz) {
      model.onCutoffFrequencyChanged(newCutoffFrequencyHz);
    })};

PlotComponent plotComponent{
    std::make_unique<MagnitudeResponsePlotViewModel>(
      model.magnitudeResponse())};
```

Example unit test

```cpp
// given
MutableObservableProperty<dsp::MagnitudeResponse> magnitudeResponse{
    /* frequencies and gains */};
MagnitudeResponsePlotViewModel testee{magnitudeResponse};

// when
testee.onPlotBoundsChanged(juce::Rectangle<int>{0, 0, 100, 100});

// then
ASSERT_EQ(juce::Path{/* correct values */}, testee.plot().value());
```


ONE DOES NOT SIMPLY
USE MVVM EVERYWHERE
imgflip.com

MVVM problems

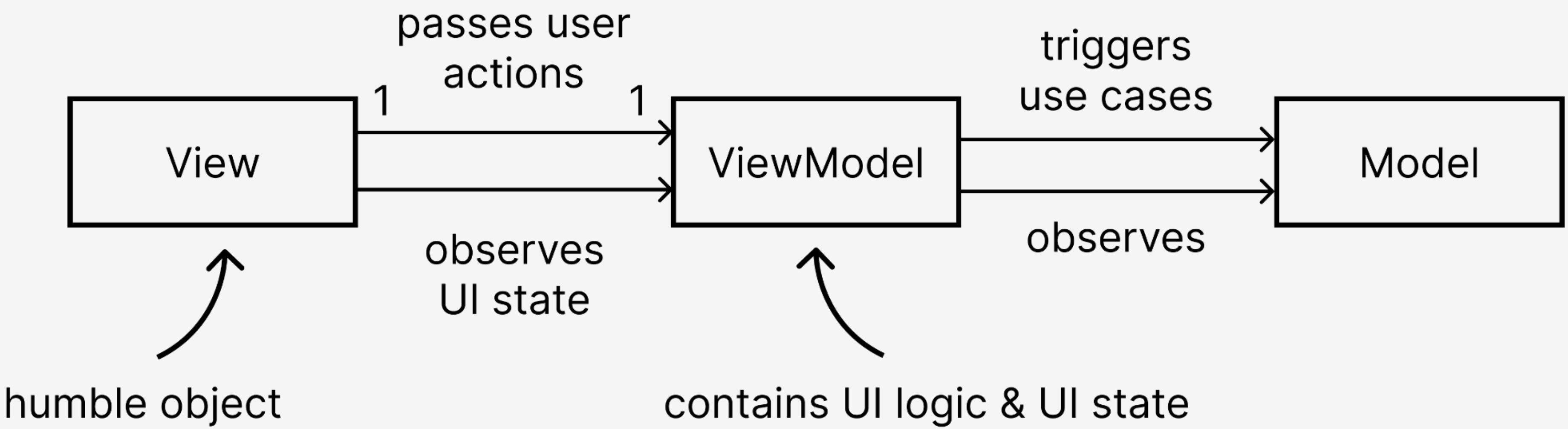
- Boiler-plate code
  - Storing connections
  - Exposing properties
- All bindings must be established
  - View → ViewModel
  - ViewModel → Model
- Model and ViewModel must not forget to notify their observers
- Requires 3rd-party libraries for implementing data binding
- Future-proof?

Recap

- You can create bug-free JUCE UIs by unit testing them.
- You can make JUCE GUIs easily testable by leveraging the MVVM pattern.
- *"Program into Your Language, Not in It"*
  - Examples: ViewModel for the Components, `ObservableProperty<T>`

Recap

- MVVM vs other GUI patterns



Recap

- MVVM enables testability of the GUI code by decoupling framework code from UI state and UI logic
- The core of MVVM is data binding
  - Examples: `ObservableProperty<T>`, `LiveObservableProperty<T>`
- MVVM can be safely applied to JUCE UIs
  - Make Components Humble Classes
  - Make Components
    - observe the ViewModel for UI state changes
    - notify the ViewModel on user actions
- MVVM supports multithreaded environments

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