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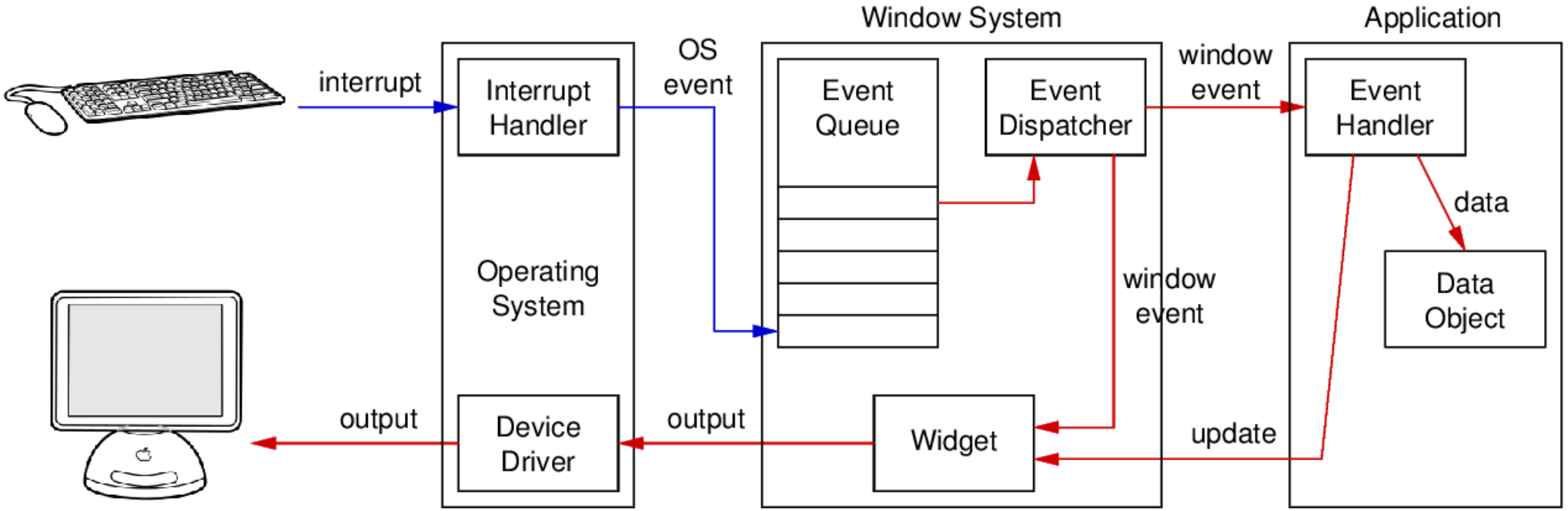
CS3249 User Interface Development

Event Processing

Events are created in response to user inputs.

Event Processing

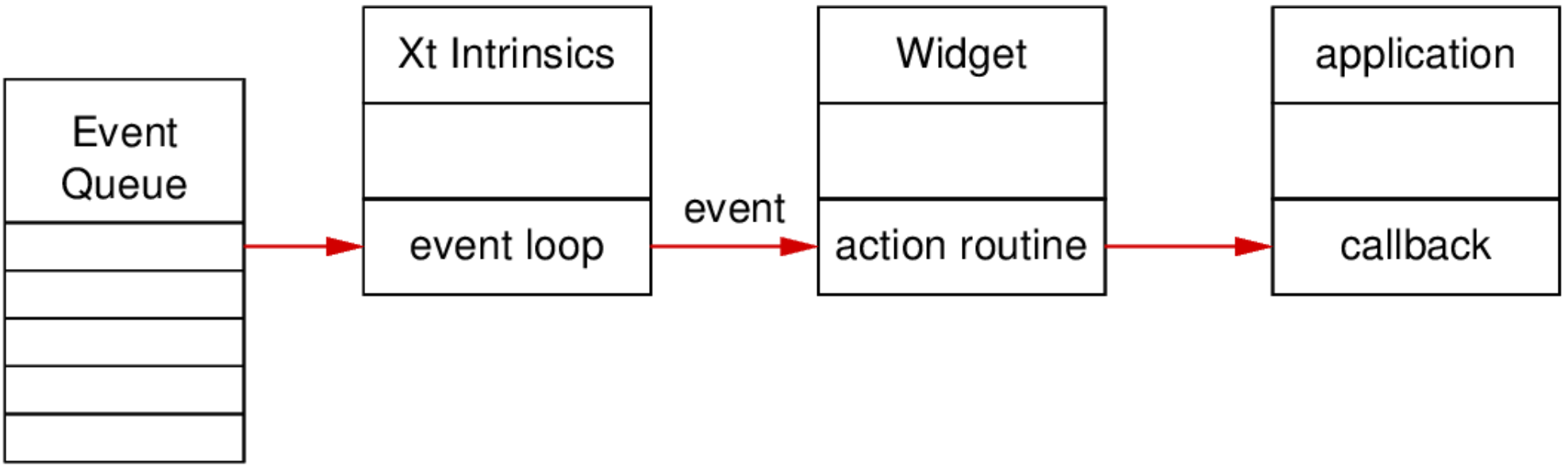


- Questions:
  - Where are the event handlers (in which part of application)?
  - Who receive events?

- Different frameworks process events differently.

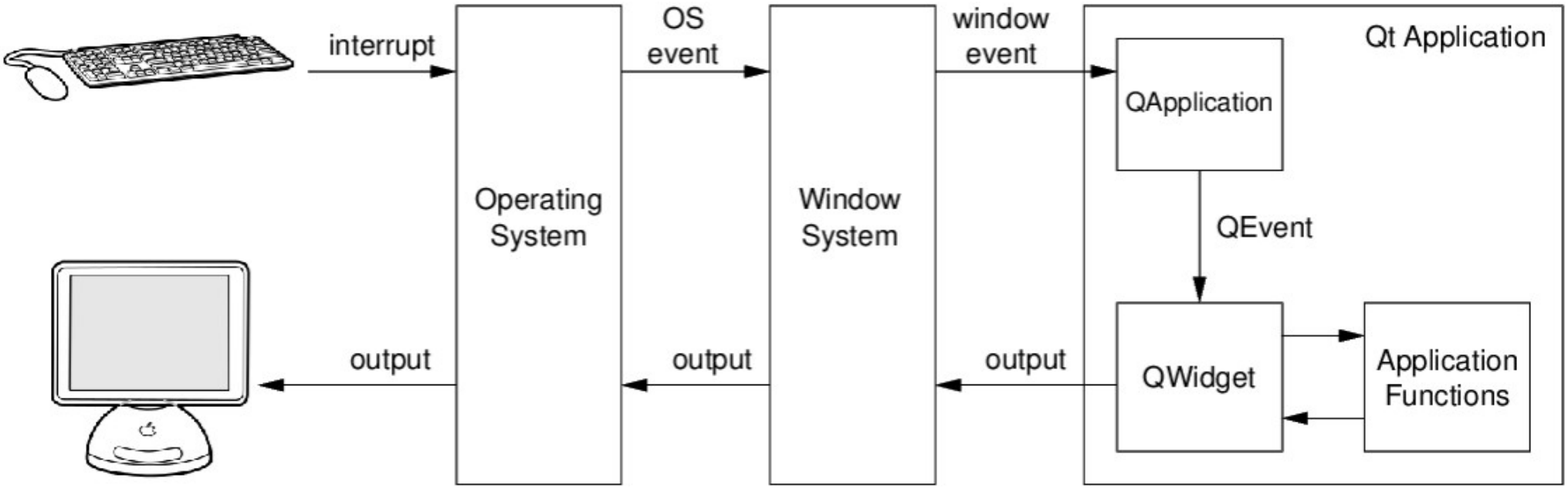
- Let's examine each of them.

X Window Event Processing



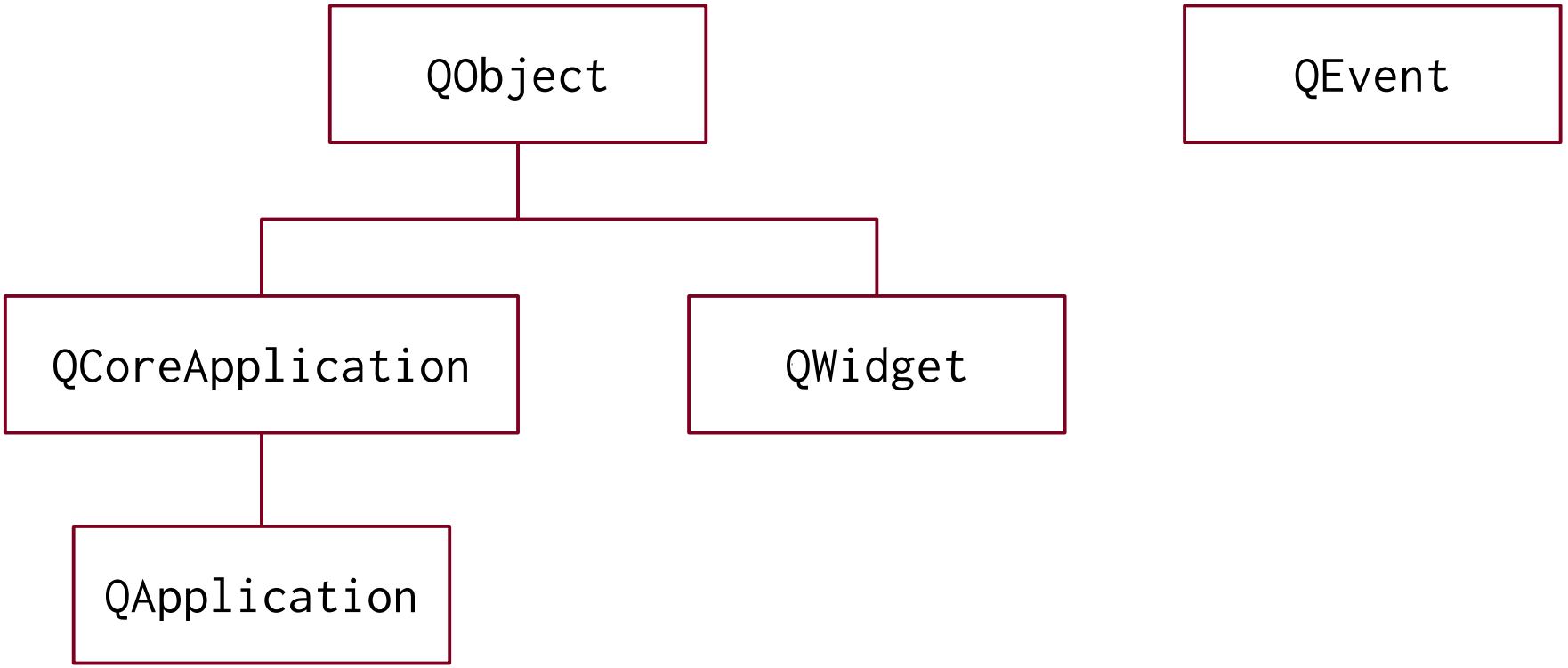
- `XtAppMainLoop()` runs event loop.
- Event is sent to widget by calling action routine.
- Action routine calls application's callback if registered.

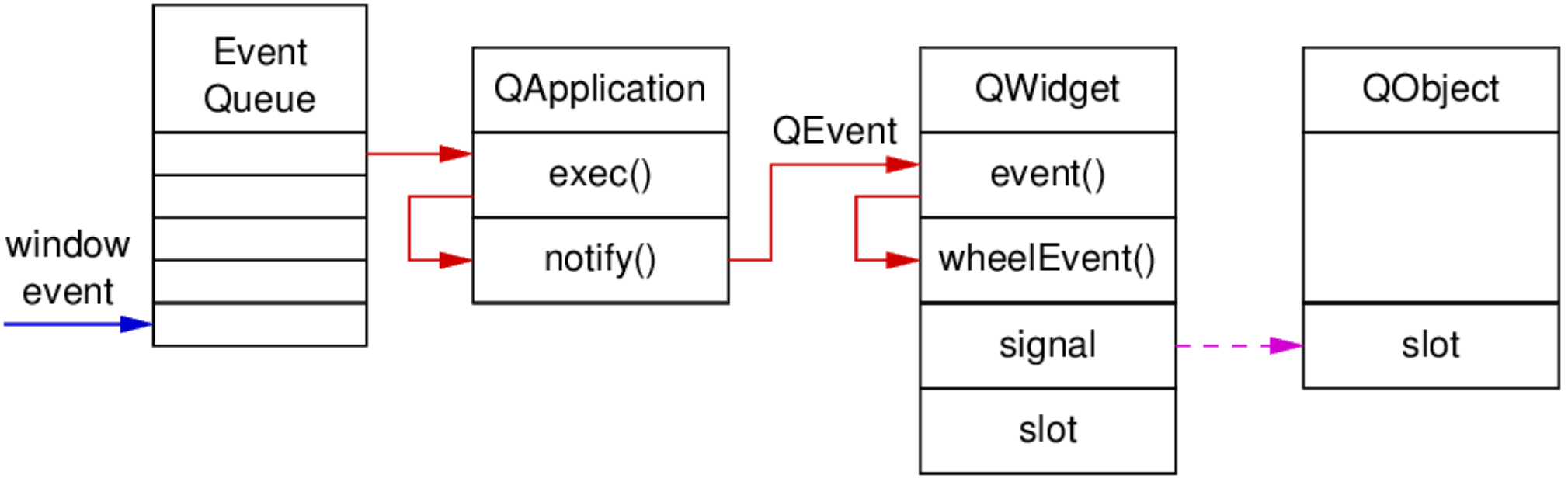
Qt Event Processing



- Qt application class
  - `QCoreApplication`: for non-GUI applications.
  - `QApplication`: for GUI applications, inherits `QCoreApplication`.
  - `qApp`: points to unique Qt application instance.

Class Hierarchy





- `QCoreApplication::exec()` runs event loop.
  - Gets native window event from event queue.
  - Translates into `QEvent` (or subclass).
  - Sends `QEvent` to `QObject` by calling `QObject::event()`.
- `QObject::event()`
  - Main event handler.
  - Forwards event to specific event handler.

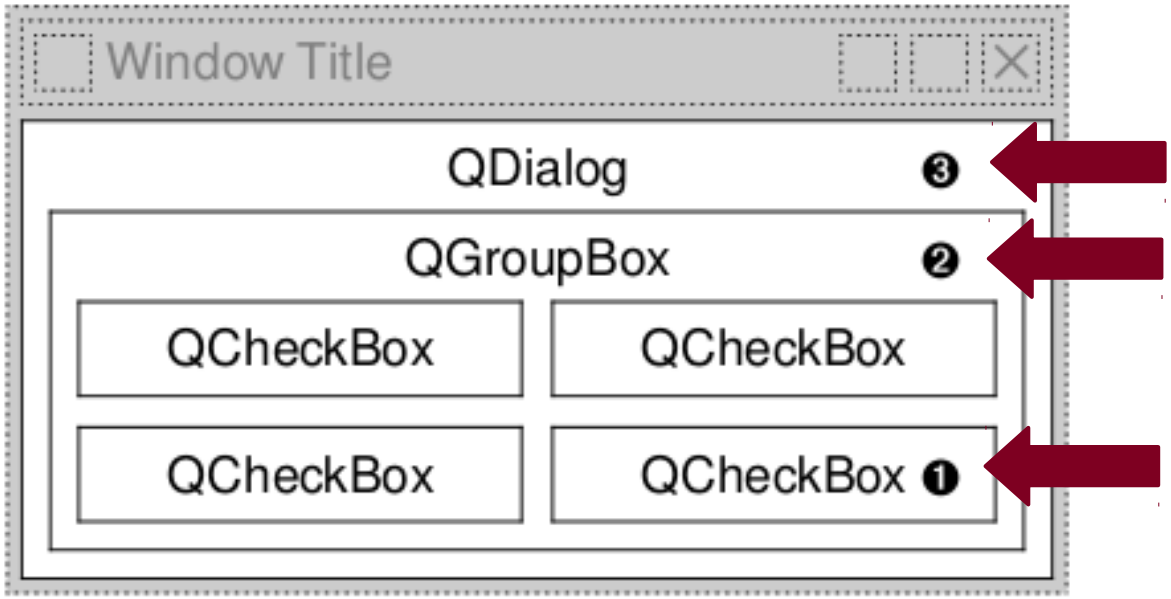
- In Qt, event ≠ signal.
  - Events are useful when implementing a widget.
    Signals are useful when using a widget.
  - Event handling is lower-level mechanism.
    Signal-slot is higher-level mechanism.

- Qt provides 5 levels of event processing:
  1. Reimplement specific event handlers.
     - Change behaviour of event handlers.
  2. Reimplement `QObject::event()` main event handler.
     - Catch events before they reach specific event handlers.
  3. Install event filer on an object.
     - Events for the object are first sent to its event filter.
  4. Install event filter on `QApplication` object.
     - All events for all objects are first sent to its event filter.
  5. Subclass `QApplication` and reimplement `notify()`.
     - Catch all events before they are sent to any event filer.

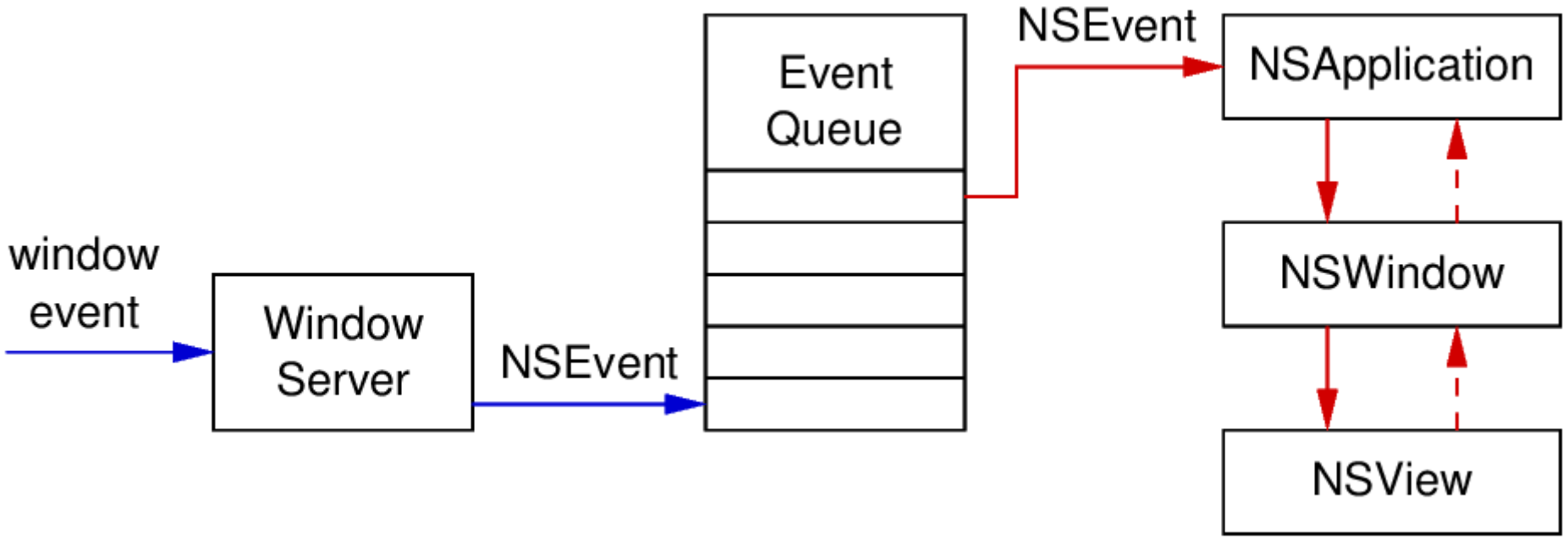
Event propagation

- Events can be propagated to parent if not handled.

```
MyWindow::mouseEvent(QMouseEvent *event)
{
    if (don't want to handle)
        QWidget::mouseEvent(event);
    else ...
}
```



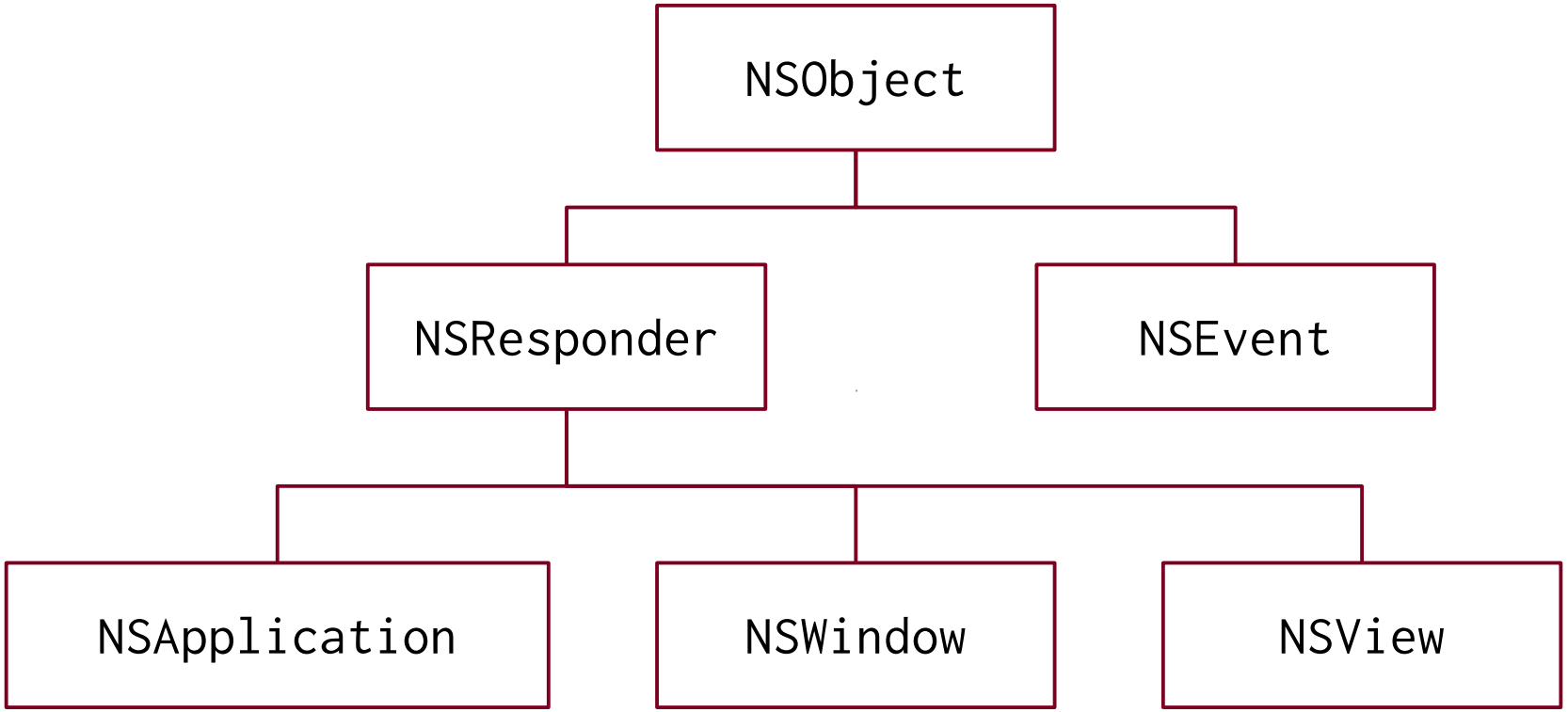
Cocoa Event Processing



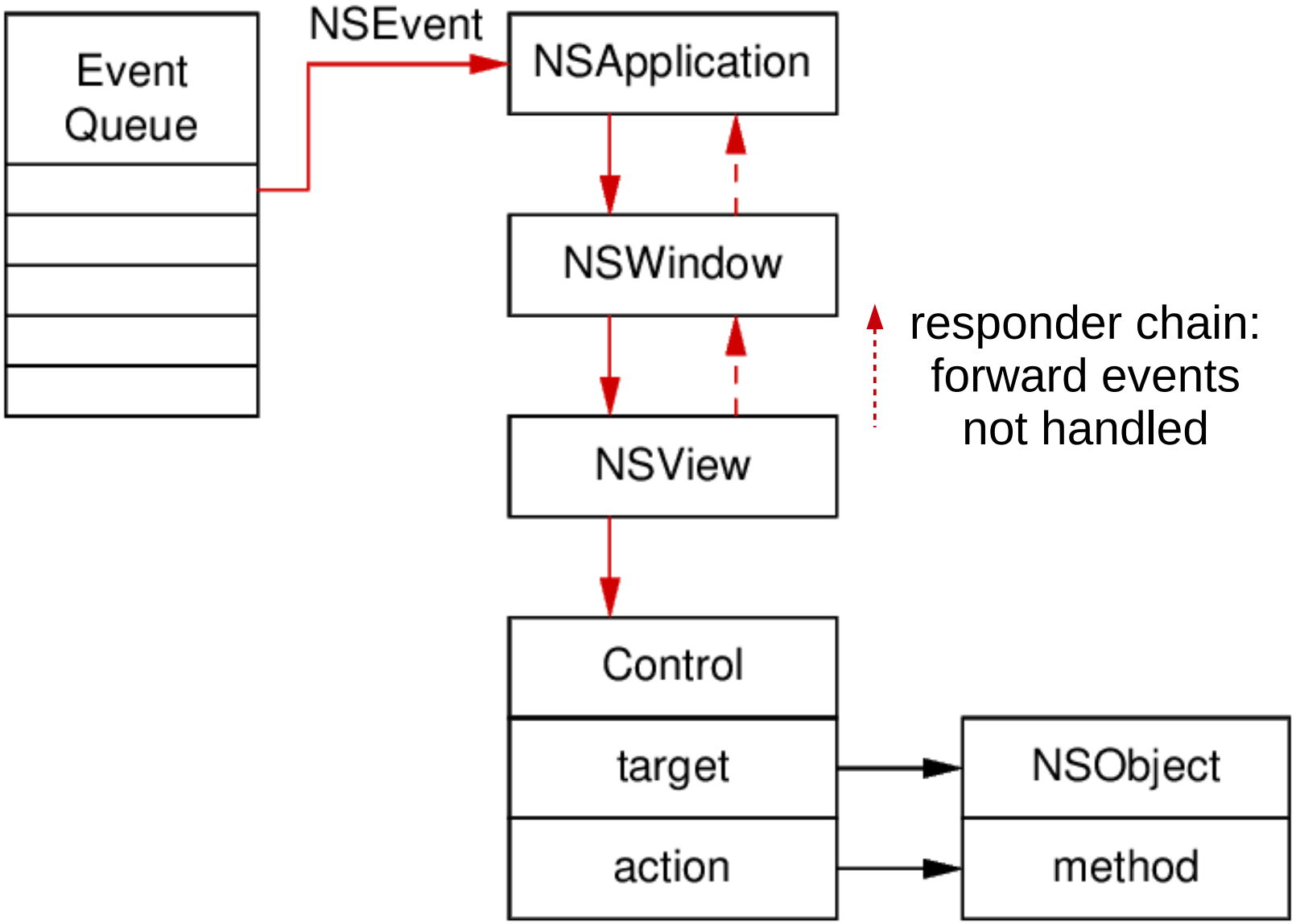
- Cocoa application class
  - `NSApplication`
  - `NSApp`: `NSApplication` object.

- Responder Model
  - `NSApplication`, `NSWindow`, `NSView` are subclasses of `NSResponder`, which can receive and handle events.
  - Event messages
    - Messages that correspond to input event, e.g., mouse click.
  - Action messages
    - Messages describing higher-level commnad, e.g., copy.
  - Responder chain
    - A series of responder objects that handle message.

Class Hierarchy



Event Routing

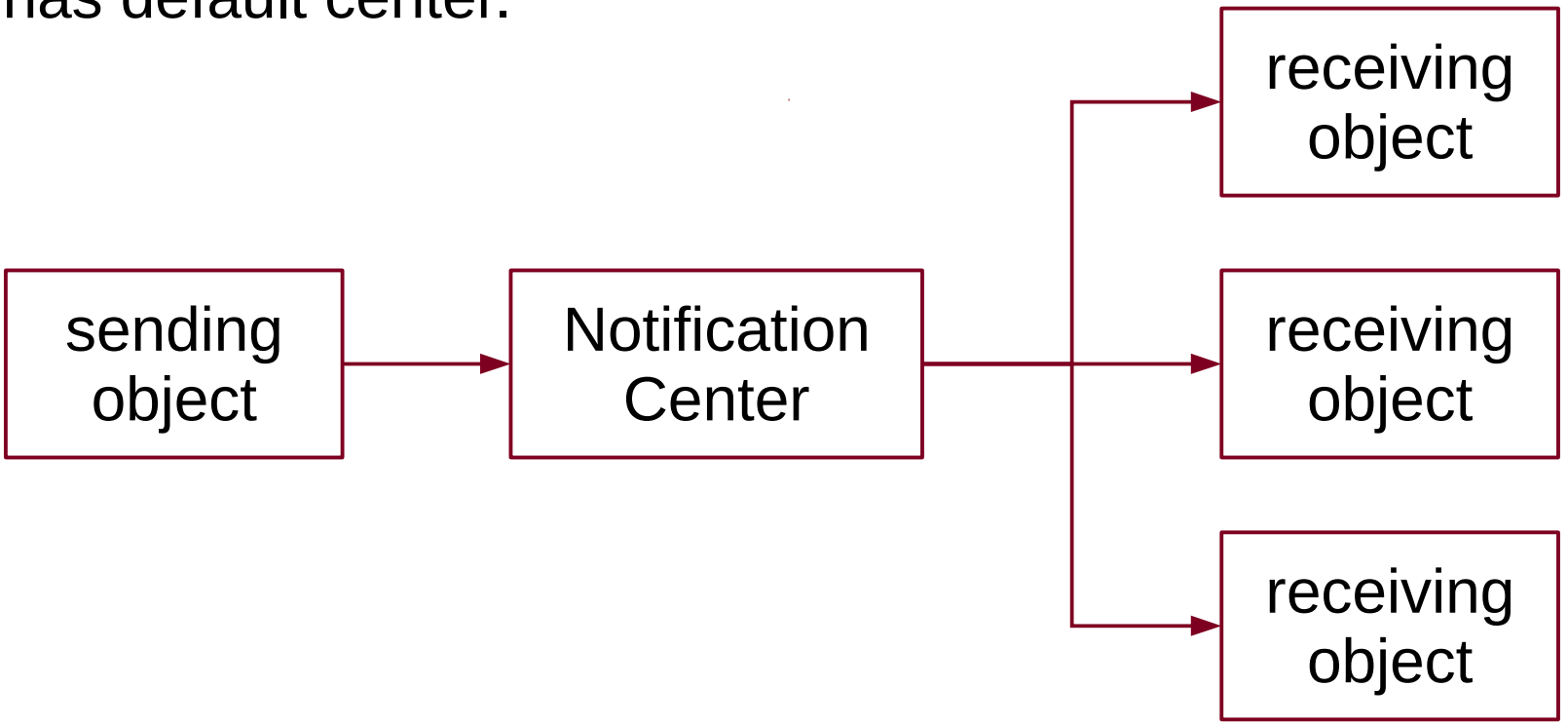


Event Delegation

- Allows an object to delegate responsibility to another.
- Delegate
  - Receives messages from another object when events occur.
  - Helps to perform tasks for sender object.
- Change object's behaviour without creating subclass.

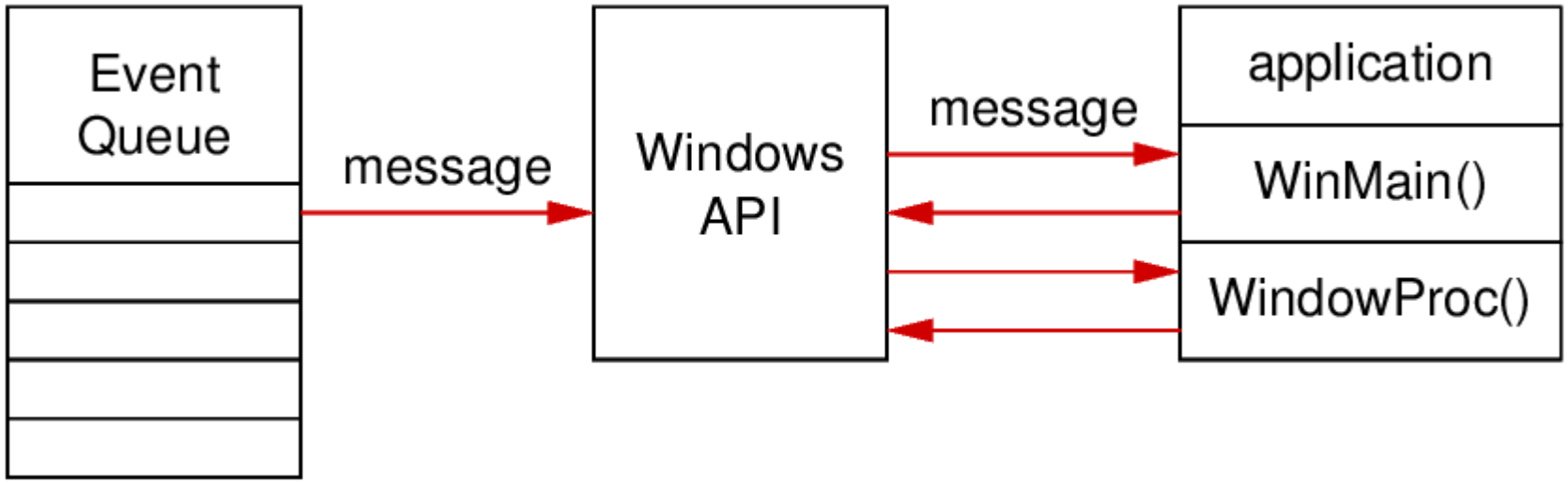
Notification

- Broadcast messages to objects in application.
- Notification center
  - Object of `NSNotificationCenter` class, has default center.



- Notification
  - Sender defines names of notifications to post as `NSString`.
  - Receiver registers with (default) notification center
    - notification to receive
    - method to invoke
  - Sender posts notification (`NSNotification`) to notification center.
  - Notification center sends notification to receiver by calling receiver's method.

Windows API Event Handling

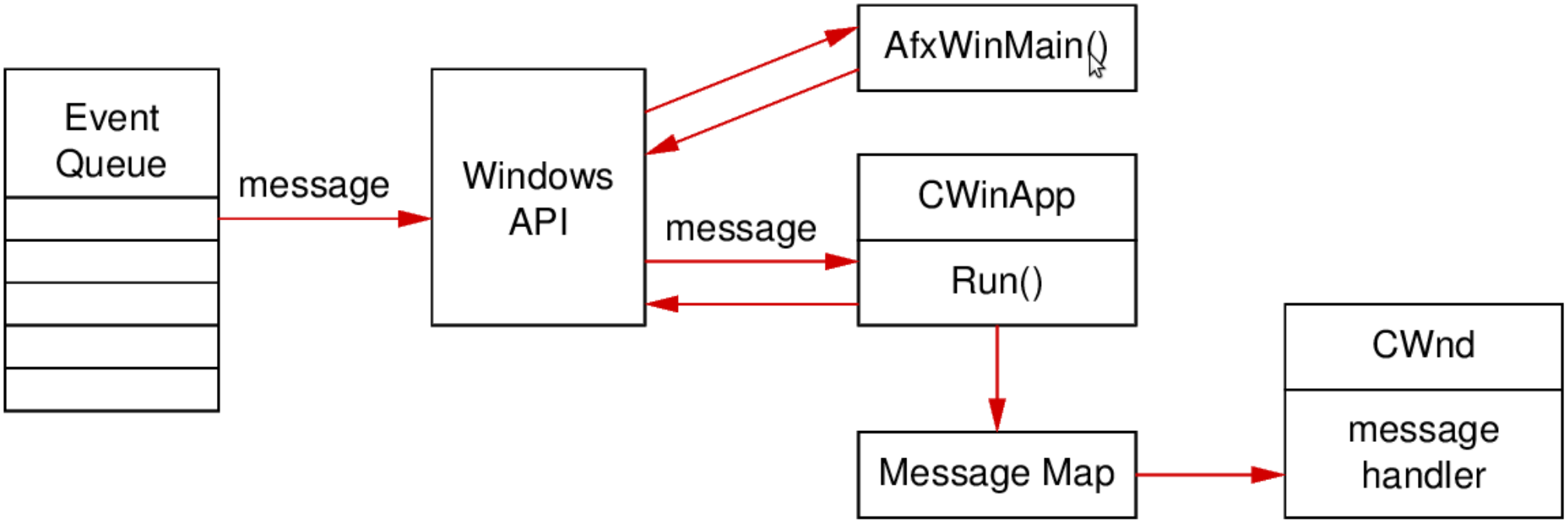


- Window API is developed in C.
- `WinMain()`
  - contains message (event) loop
- `WindowProc()`
  - main message (event) handler

```
int WINAPI WinMain(HINSTANCE instance, HINSTANCE notused,
    LPSTR commandLine, int showOptions)
{
    WNDCLASS WindowClass;
    ... // set WindowClass parameters
    RegisterClass(&WindowClass);

    window = CreateWindow(...);
    ShowWindow(window, showOptions);
    UpdateWindow(window);

    // message loop
    MSG msg;
    while(GetMessage(&msg, 0, 0, 0) == TRUE)
    {
        TranslateMessage(&msg);
        DispatchMessage(&msg);
    }
    return static_cast<int>(msg.wParam);
}
```

```
LRESULT CALLBACK WindowProc(HWND window, UINT msgId,
    WPARAM wParam, LPARAM lParam)
{
    switch(msgId)
    {
        case WM_CREATE:
            ... // create window
            return 0;

        case WM_DESTROY:
            PostQuitMessage(0);
            return 0;

        default: // call default message handler
            return DefWindowProc(window, msgId, wParam,
                lParam);
    }
}
```

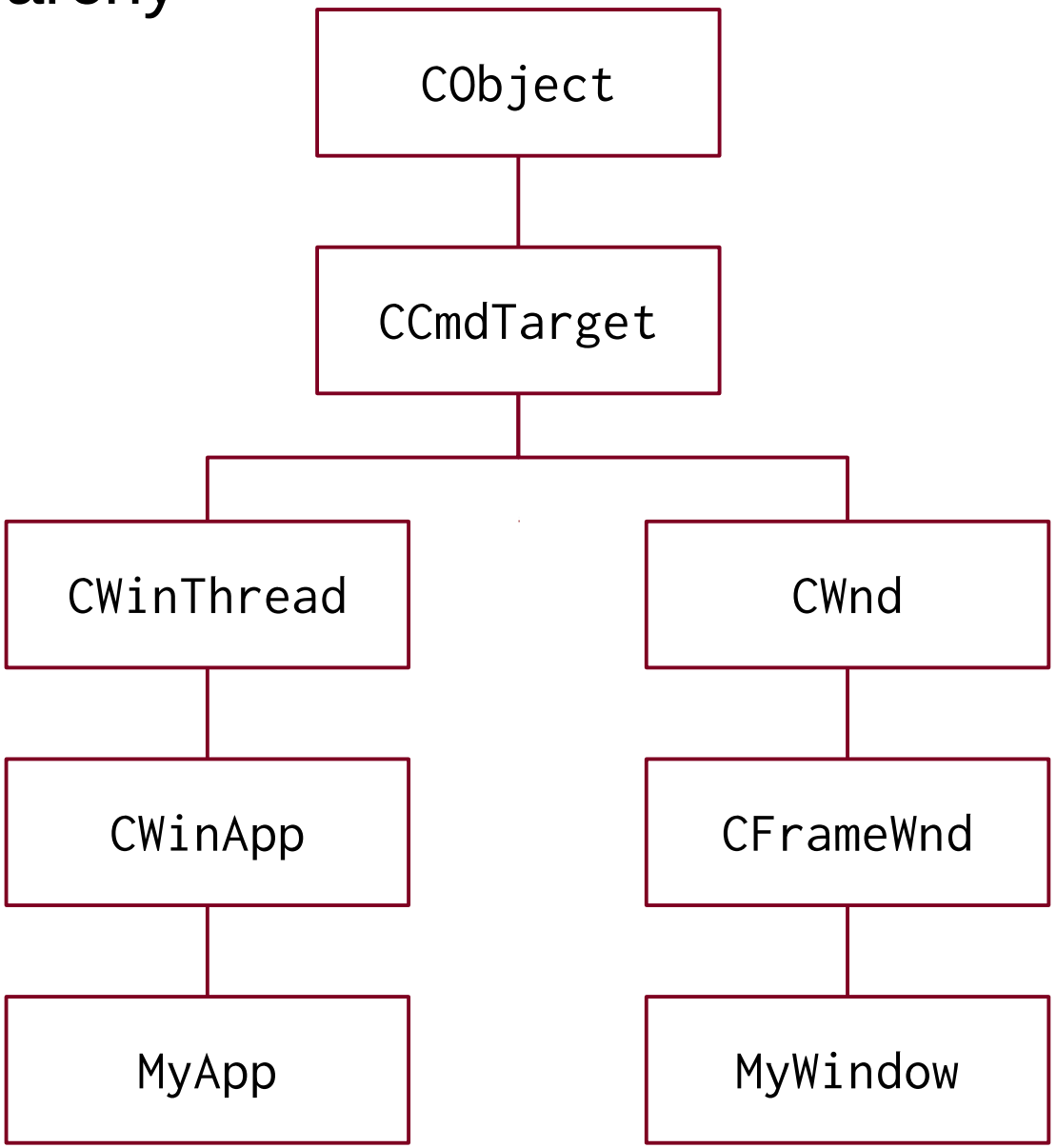
MFC Event Handling



MFC encapsulates Windows API in C++ classes.

- `CWinApp::Run()` runs message (event) loop.
- `CWinApp` and `CWnd` have message (event) handlers.

Class Hierarchy

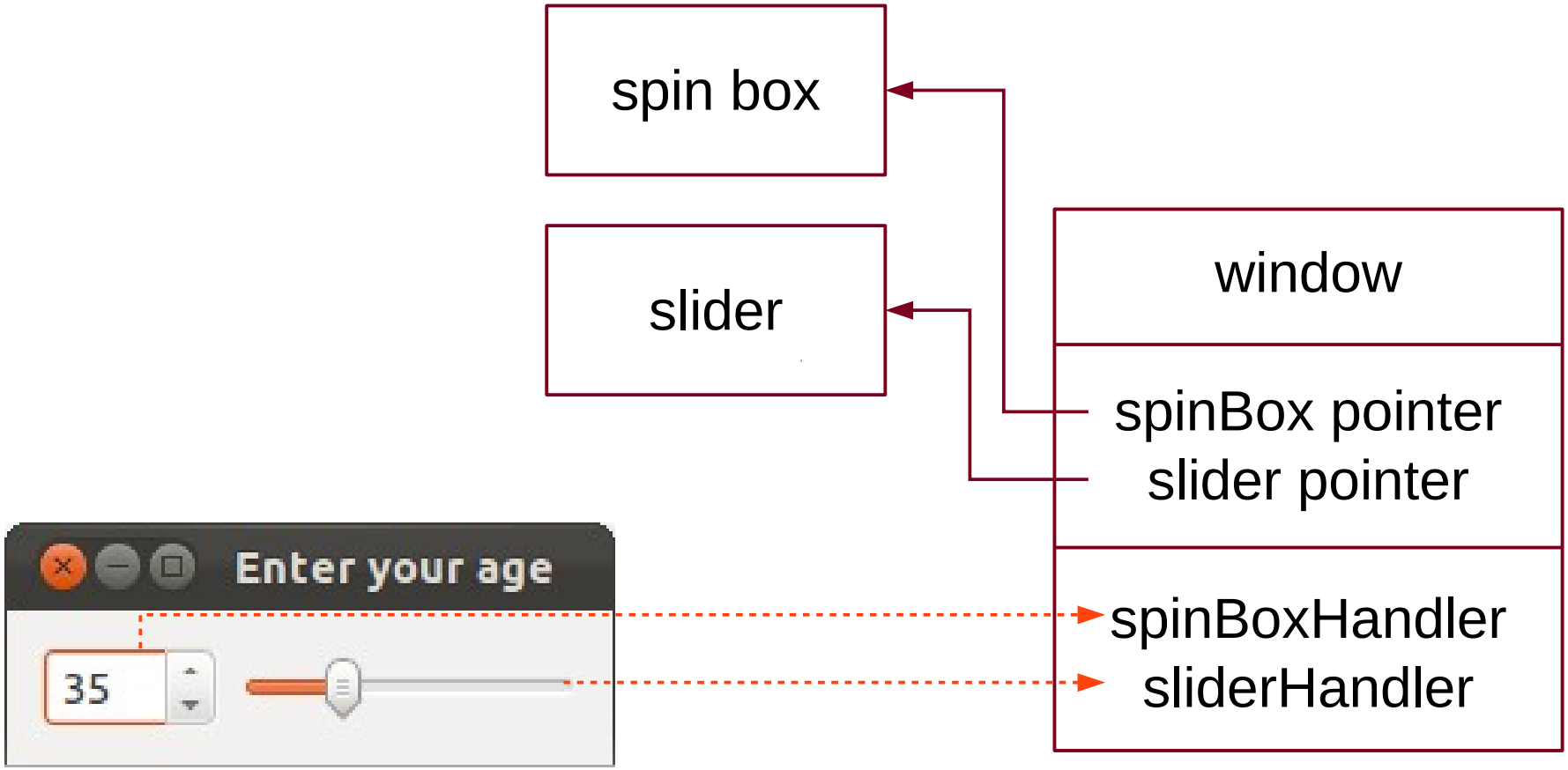


Event Receiver

Two kinds

- Top-level window
  - Examples: Windows API / MFC, ...
- Widget / object
  - Examples: X, Qt, Cocoa

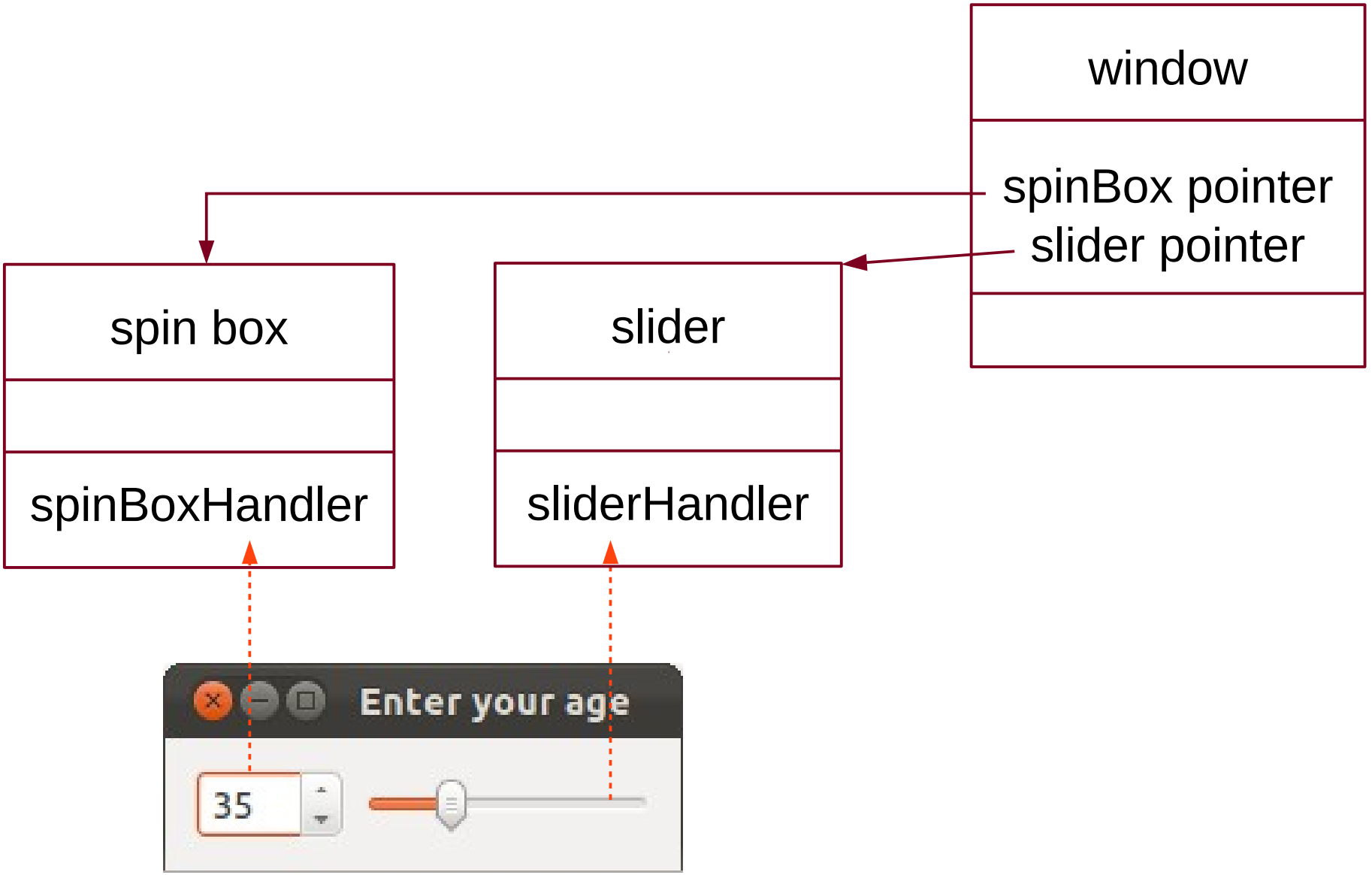
Top-Level Window Handles Events



- Advantages
  - Top-level window contains all UI elements.
  - Easy to synchronise states of UI elements.
  - Simple mechanism.

- Disadvantages
  - Top-level window is tightly coupled to UI elements.
  - UI elements' functions are incomplete;
    some are in top-level window (low cohesion).
  - Cannot define part of the window as widget for reuse.

Widget Handles Events



- Advantages
  - Top-level window can be loosely coupled to UI elements.
  - UI elements' functions are more complete (high cohesion).
  - Can define part of the window as widget for reuse.
  - Powerful mechanism.

- Complication
  - How to coordinate actions of UI elements?
    - Centralised at top-level window
      - Simple but tight coupling with UI elements.
    - Decentralised to UI elements
      - Possible tight coupling between UI elements, or need observer mechanism.

- X Window's solution: callback
  - Application synchronises states of UI elements.
    - Easy to use, but tightly coupled.
- Cocoa's solution: target-action
  - Top-level window synchronises states of UI elements.
    - Easy to use, but tightly coupled.
- Qt's solution: signal-slot 
  - Widgets synchronise their states by signals and slots.
    - Easy to use, and yet loosely coupled.

Comparison

	Qt	X11/Motif	Cocoa	MFC
event loop	`QApplication ::exec()`	`XtAppMainLoop()`	in `NSApplication`	`CWinApp:: Run()`
event receiver	`QWidget`	widget, application	target object, top-level window	top-level window
event handler	`QWidget` event handler	widget's action routine, application's callback	target's action function	top-level window message handler
synchroni-sation	signal-slot	application	target top-level window	top-level window

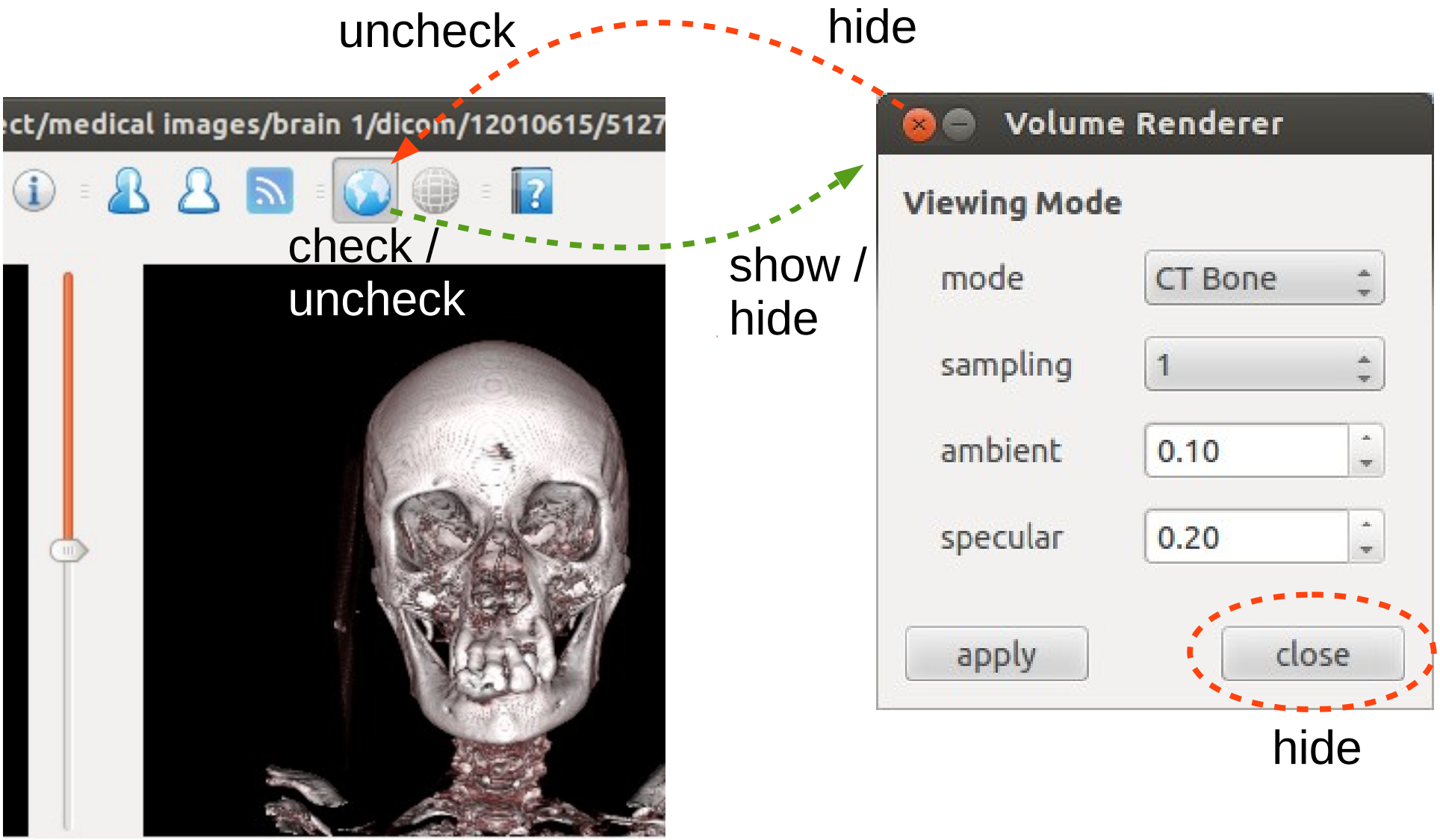
Qt Event Handlers

- Reimplement event handlers
  - We have used this technique before.
  - We'll see more of it in later lectures.

```
void MyEditor::closeEvent(QCloseEvent *event)
{
    if (okToContinue())
        event->accept();
    else
        event->ignore();
}
```

  - `closeEvent()` is reimplemented in `MyEditor`.
  - `QCloseEvent` is a subclass of `QEvent`.

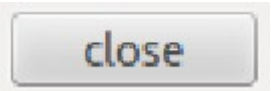
Qt Event Filter



- Two ways to create volume render dialog:
  - Subclass
    - `VolumeRenderDialog` as subclass of `QWidget`
    - `QWidget` does not emit close signal when hiding.
    - Define `closed()` signal in `VolumeRenderDialog`.
    - Use `closed()` to uncheck action.
  - Composition
    - `VolumeRenderDialog` is a `QWidget` in main window.
    - Use close button's `clicked()` signal to uncheck action.
    - Use event filter to catch close event and uncheck action.

Subclass Method

```
class VolumeRenderDialog:: public QWidget
{
    Q_OBJECT

public:
    VolumeRenderDialog();
    ...

protected:
    void closeEvent(QCloseEvent *event);

signals:
    void closed();
    ...
};
```

- Hide by clicking close button: 


```
void VolumeRenderDialog::createWidgets()
{
    QPushButton *closeButton = new QPushButton("close");
    ...
    connect(closeButton, SIGNAL(clicked()),
        this, SLOT(hide()));
    connect(closeButton, SIGNAL(clicked()),
        this, SIGNAL(closed())); // emit signal
}
```

- Hide by clicking close window button: 

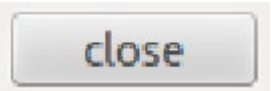
```
void VolumeRenderDialog::closeEvent(QCloseEvent *event)
{
    event->accept();
    emit closed();
}
```

```
class MainWindow:: public QMainWindow
{
    Q_OBJECT

public:
    MainWindow();
    ...

private:
    QAction *volumeRenderAction;
    VolumeRenderDialog *volumeRenderDialog;
    ...
};
```

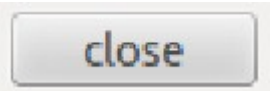
```
void MainWindow::createWidgets()
{
    volumeRenderDialog = new VolumeRenderDialog;
    ...
}

void MainWindow::createActions()
{
    volumeRenderAction = new QAction("Volume Render",
        this);
    volumeRenderAction->setCheckable(true);
    ...
    connect(volumeRenderAction, SIGNAL(toggled(bool)),
        volumeRenderDialog, SLOT(setVisibility(bool)));
    connect(volumeRenderDialog, SIGNAL(closed()),
        VolumeRenderAction, SLOT(toggle()));
}
```

Composition Method

```
class MainWindow:: public QMainWindow
{
    Q_OBJECT

public:
    MainWindow();
    ...

protected:
    bool eventFilter(QObject *object, QEvent *event);

private:
    QAction *volumeRenderAction;
    QWidget *volumeRenderDialog;
    ...
};
```

- Hide by clicking close button: 


```
void MainWindow::createWidgets()
{
    volumeRenderDialog = new QWidget;
    volumeRenderDialog->installEventFilter(this);

    QPushButton *closeButton = new QPushButton(“close”);
    ...
    connect(closeButton, SIGNAL(clicked()),
        volumeRenderDialog, SLOT(hide()));
    ...
}
```

- Hide by clicking close button: 


```
void MainWindow::createActions()
{
    volumeRenderAction = new QAction("Volume Render",
        this);
    volumeRenderAction->setCheckable(true);
    ...
    connect(volumeRenderAction, SIGNAL(toggled(bool)),
        volumeRenderDialog, SLOT(setVisibility(bool)));
    connect(closeButton, SIGNAL(clicked()),
        volumeRenderAction, SLOT(toggle()));
}
```

- Hide by clicking close window button: 

```
bool MainWindow::eventFilter(QObject *object,
    QEvent *event)
{
    if (object == volumeRenderDialog)
        if (event->type() == QEvent::Close)
        {
            volumeRenderAction->setChecked(false);
            return false; // Let volumeRenderDialog
                          // handle close event
        }

    // Let parent widget handle event.
    return QMainWindow::eventFilter(object, event);
}
```

Staying Responsive

- Event processing should be fast.
  - Other events are waiting to be dispatched and processed.
  - Slow event processing can freeze the whole GUI.
- But some processes just need more time.
  - Example: Saving a large spread sheet into disk.
- Possible solutions
  - Show wait cursor to inform the user to just wait.
  - Call dispatcher to dispatch events regularly.
  - Run long operations when system is idle (further reading).
  - Use multithreading (later lecture).
  - Use lazy evaluation, level-of-details (later lecture).

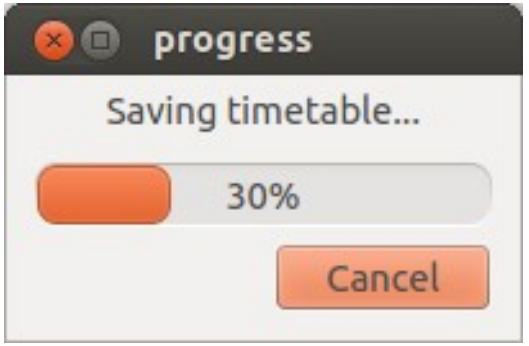
```
bool Spreadsheet::writeFile(const QString &fileName)
{
    QFile file(fileName);
    QTextStream out(&file);

    for (int row = 0; row < RowCount; ++row)
    {
        for (int col = 0; col < ColumnCount; ++col)
        {
            QString str = formula(row, col);
            if (!str.isEmpty())
                out << quint16(row) << quint16(col) << str;
        }

        qApp->processEvents();  // Dispatch some events.
    }
    return true;
}
```

- Calling `qApp->processEvents()` is a bit dangerous
  - User may close the application while it is writing.
  - Solution:

```
qApp->processEvents(
    QEventLoop::ExcludeUserInputEvents);
```

    - Ignore key and mouse inputs.

- For long-running process, can show progress dialog.




```
bool Spreadsheet::writeFile(const QString &fileName)
{
    QFile file(fileName);
    QTextStream out(&file);

    QProgressDialog progress(this);
    progress.setLabelText(tr("Saving %1").arg(fileName));
    progress.setRange(0, RowCount);
    progress.setModal(true);
```

```
    for (int row = 0; row < RowCount; ++row)
    {
        progress.setValue(row);  // Update progress bar.
        qApp->processEvents();   // Dispatch some events.

        if (progress.wasCanceled())
        {
            file.remove();
            return false;
        }

        for (int col = 0; col < ColumnCount; ++col)
        {
            QString str = formula(row, col);
            if (!str.isEmpty())
                out << quint16(row) << quint16(col) << str;
        }
    }
    return true;
}
```

Timer Event

- Timer events are delivered at “regular interval”.
  - Allow applications to perform processing at regular interval.
  - Implement blinking cursors, animations, video player, etc.
- Illustrate with an animated banner

```
// Ticker.h

#ifndef TICKER_H
#define TICKER_H

#include <QWidget>

class Ticker : public QWidget
{
    Q_OBJECT
    Q_PROPERTY(QString text READ text WRITE setText)

public:
    Ticker(QWidget *parent = 0);
    QString text() const { return myText; }
    void setText(const QString &newText);
    QSize sizeHint() const;
```

```
protected:
    void paintEvent(QPaintEvent *event);
    void timerEvent(QTimerEvent *event);
    void showEvent(QShowEvent *event);
    void hideEvent(QHideEvent *event);

private:
    QString myText;
    int offset;
    int myTimerId;
};

#endif
```

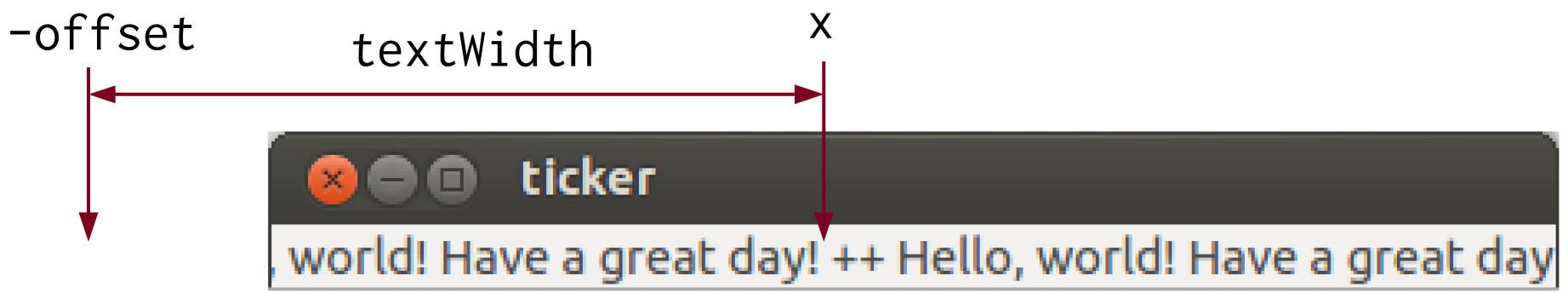
- Reimplement 4 event handlers.

```
// Ticker.cpp

#include <QtGui>
#include "Ticker.h"

Ticker::Ticker(QWidget *parent): QWidget(parent)
{
    offset = 0;
    myTimerId = 0;  // Indicate no timer has started.
}


void Ticker::setText(const QString &newText)
{
    myText = newText;
    update();  // Repaint.
    updateGeometry();  // Update if size has changed.
}
```

```
QSize Ticker::sizeHint() const
{
    return fontMetrics().size(0, text());
}
```

- `fontMetrics()` returns `QFontMetrics` object.
  - Use it to check info about the widget's font.
- `fontMetrics().size()` returns pixel length of `text()`.
  - First argument is not needed; so set to 0.

```
void Ticker::paintEvent(QPaintEvent * /* event */)
{
    QPainter painter(this);
    int textWidth = fontMetrics().width(text());
    if (textWidth < 1)
        return;

    int x = -offset; // Start position offset to the left.
    while (x < width()) // Repeat while have space
    {
        painter.drawText(x, 0, textWidth, height(),
            Qt::AlignLeft | Qt::AlignVCenter, text());
        x += textWidth;
    }
}
```



```
void Ticker::showEvent(QShowEvent * /* event */)
{
    myTimerId = startTimer(30);
}
```

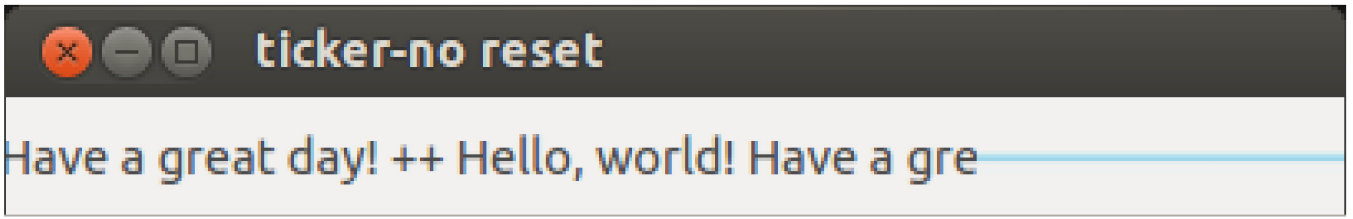
- Starts timer when widget is visible.
- Qt will generate a timer event once every 30 msec.

```
void Ticker::hideEvent(QHideEvent * /* event */)
{
    killTimer(myTimerId);  // Stops timer.
}
```

```
void Ticker::timerEvent(QTimerEvent *event)
{
    if (event->timerId() == myTimerId)
    {
        ++offset;
        if (offset >= fontMetrics().width(text()))
            offset = 0;
        scroll(-1, 0);
    }
    else
        QWidget::timerEvent(event);  // propagate
}
```

- `scroll(-1, 0)` scrolls text displayed in widget left by one pixel.
  - It generates paint event only for newly revealed 1-pixel strip.
  - More efficient than calling `update()`.

- `offset` is increased and reset to 0
- Without resetting `offset`



```
// main.cpp

#include <QApplication>
#include "Ticker.h"

int main(int argc, char *argv[])
{
    QApplication app(argc, argv);
    Ticker *ticker = new Ticker;
    ticker->setText("++ Hello, world! Have a great day! ");
    ticker->show();
    return app.exec();
}
```

- Notes on using `QTimer`:
  - Timer events are delivered after, not before, period is up.
  - Timer events are delivered only when event loop is running.
    - When an operation is executing, timer event is not delivered until control returns to event loop.
  - Timer resolution depends on operating systems:
    - Some support 1 msec interval,
      some support 15 msec interval.

Summary

- Handle events in response to user actions.
- Event receiver
  - Top-level window: common type.
  - Any object / widget: more sophisticated type.
- Qt event handling
  - Reimplement event handler to change behaviour.
  - Install event filter to catch event.
- If long-running, clear event queue regularly.
- Use timer event for regular activities.

Further Reading

- Event processing details: [Blan2008] chap. 7.
- User timer event to indicate system idle: [Blan2008] chap. 7.
- Installing event filter: [Blan2008] chap. 7.

References

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