



# 13<sup>th</sup> Summer School on **SCIENTIFIC** VISUALIZATION

## Introduction to GUI development using Qt

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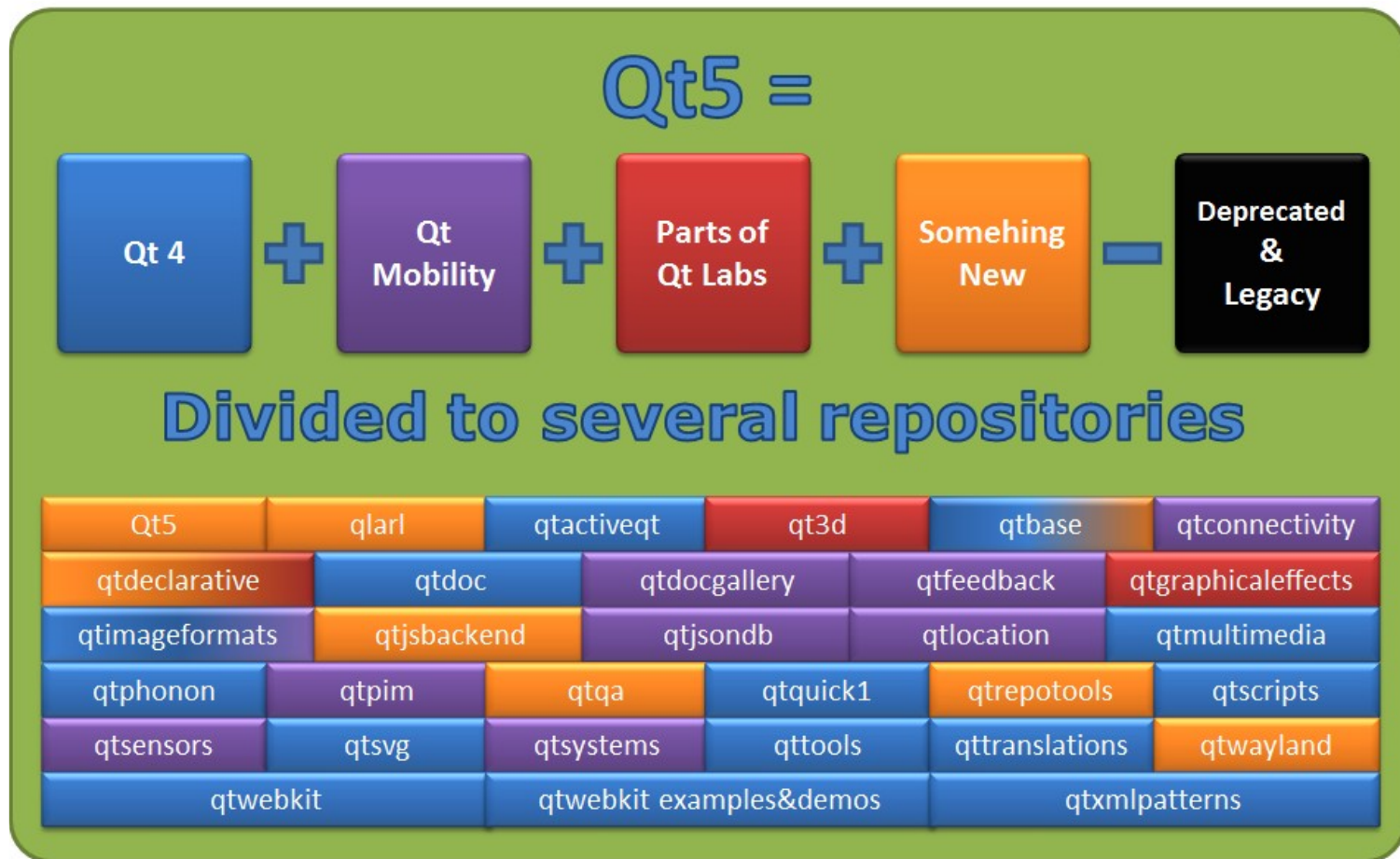


# What is Qt

- Qt is a cross-platform development framework written in C++
- Can be used in several programming languages through bindings
  - Ruby
  - Java
  - Perl
  - Python → **PyQt**
- The Qt Toolkit is a collection of classes for various purposes
  - Database management
  - XML
  - WebKit
  - Multimedia
  - Networking
  - ...
- For **desktop**, **mobile** and **embedded** development
  - Used by more than 350,000 **commercial** and **open source** developers
  - Backed by Qt consulting, support and training
  - Trusted by over 6,500 companies worldwide



# Qt modules





# Qt brief timeline

- Qt Development Frameworks founded in 1994
- Trolltech acquired by Nokia in 2008
- Qt Commercial business acquired by Digia in 2011
- Qt business acquired by Digia from Nokia in 2012



# Why Qt

- Write code once to target multiple platforms
- Produce compact, high-performance applications
- Focus on innovation, not infrastructure coding
- Choose the license that fits you
  - Commercial, LGPL or GPL
- Count on professional services, support and training



# PyQt

- PyQt is a set of Python bindings for Qt framework
  - Bindings implemented as Python modules (620+ classes)
  - Almost the entire Qt library is available
- Take advantage of both languages key strength
  - Python: easy to learn, lot of extensions, no compilation required
  - Qt: abstraction of platform-specific details, GUI designer



# “Hello world” in PyQt 1/2

```
from PyQt4.QtCore import *  
from PyQt4.QtGui import *  
import sys
```

```
app = QApplication(sys.argv)
```

```
PushButton = QPushButton("Hello World")  
PushButton.show()
```

```
sys.exit(app.exec_())
```



# “Hello world” in PyQt 2/2

- \* **sys** module needed to access command-line arguments
- \* **QtCore** and **QtGui** (from PyQt4 library) contains GUI widgets
- \* Every PyQt application must have a **QApplication** object
- \* Create a new instance of a **QPushButton**
- \* Call **show()** to schedule a “paint event”
- \* The call to **app.exec\_()** starts the event loop





# Core types



# QObject

**QObject** is the heart of Qt's object model

Include these features:

- Memory management
- Object properties
- Introspection
- Signals and slots
- Event handling

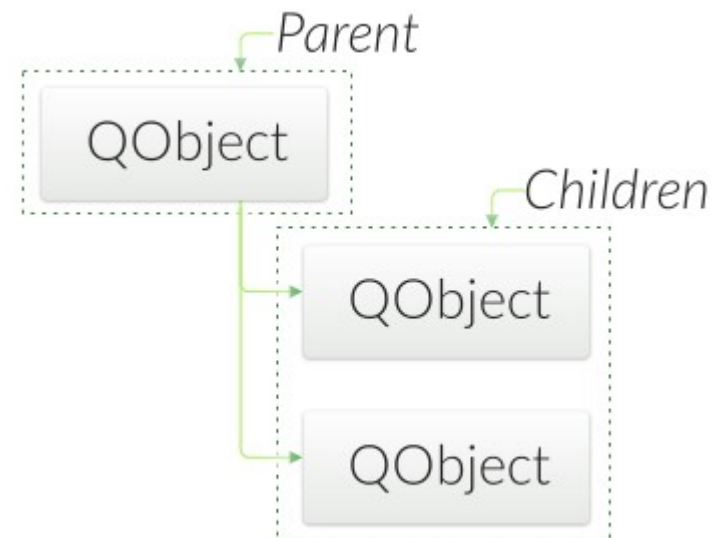
QObject has no visual representation



# Object tree

- QObjects organize themselves in object trees
  - Based on parent-child relationship
- QObject (QObject \*parent = 0)
- Parent adds object to list of children
- Parent owns children
- Used intensively with QWidget

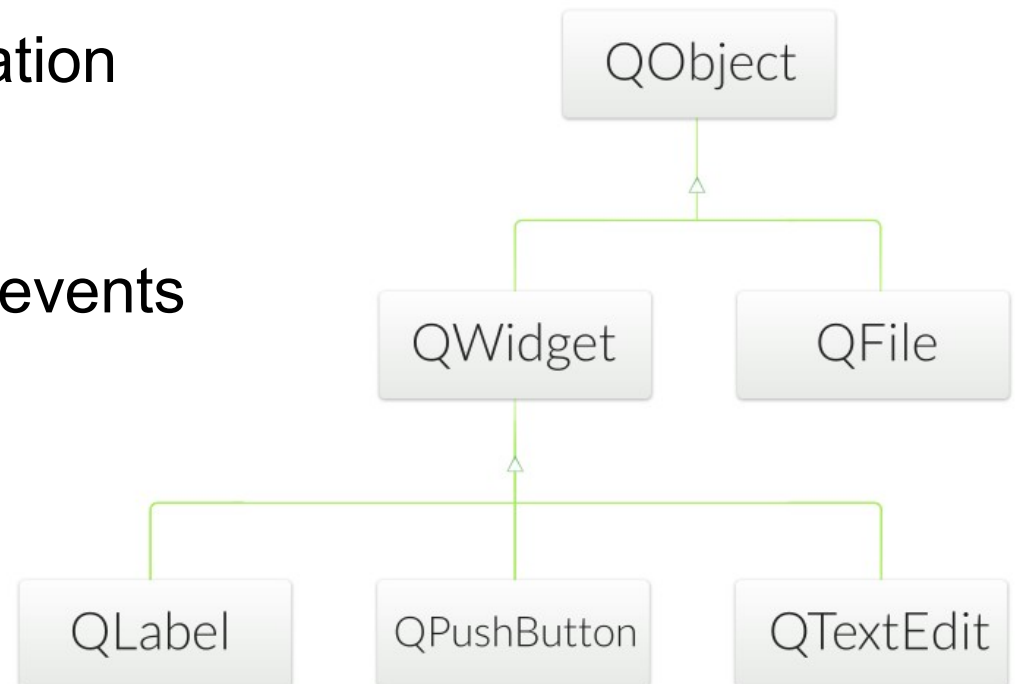
**Parent-child relationship  
IS NOT inheritance!**





# Qt's Widget Model - QWidget

- Derived from QObject
  - Adds visual representation
- Receives events
  - e.g. mouse, keyboard events
- Paints itself on screen
  - Using styles





# Object Tree and QWidget

- `new QWidget(0)`
  - Widget with no parent = "window"
- QWidget children
  - Positioned in parent's coordinate system
  - Clipped by parent's boundaries
- QWidget parent
  - Propagates state changes
  - hides/shows children when it is hidden/shown itself
  - enables/disables children when it is enabled/disabled itself





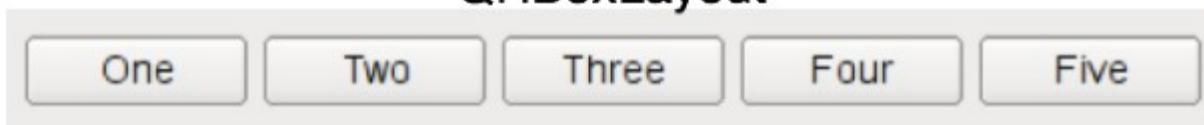
# Widgets containing other widgets

- **Container Widget**
  - Aggregates other child-widgets
- **Use layouts for aggregation**
  - QHBoxLayout, QVBoxLayout, QGridLayout
  - Note: Layouts are not widgets
- **Layout Process**
  - Add widgets to layout
  - Layouts may be nested
  - Set layout on container widget
  - Hint: use QtDesigner to apply layouts!

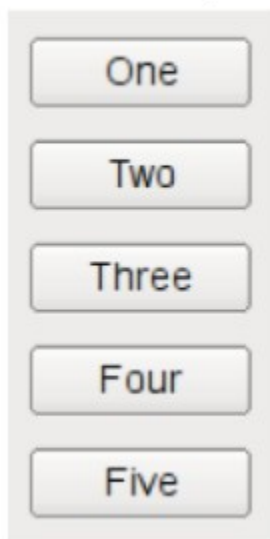


# Layout: examples

QHBoxLayout



QVBoxLayout



QGridLayout





# Object communication

- Between objects
  - Signals & Slots
- Between Qt and the application
  - Events
- Between Objects on threads
  - Signal & Slots + Events





# Callbacks

## General Problem

*How do you get from "the user clicks a button" to your business logic?*

## Possible solutions:

- **Callbacks**
  - Based on function pointers
  - Not type-safe
- **Observer Pattern (Listener)**
  - Based on interface classes
  - Needs listener registration
  - Many interface classes
- **Qt uses**
  - Signals and slots for high-level (semantic) callbacks
  - Virtual methods for low-level (syntactic) events.



# Signals and slots

- Every PyQt object deriving from QObject supports S&S mechanism
- Widgets emit **signals**
- A signal announce state changes:
  - a button was clicked
  - a checkbox is checked/unchecked
  - editing in a text field finished
- Widgets react to a signal through **slots**
- **Connections** are used to link signals and slots



# Signals & Slots 1/8



42



# Signals & Slots 2/8



42



# Signals & Slots 3/8



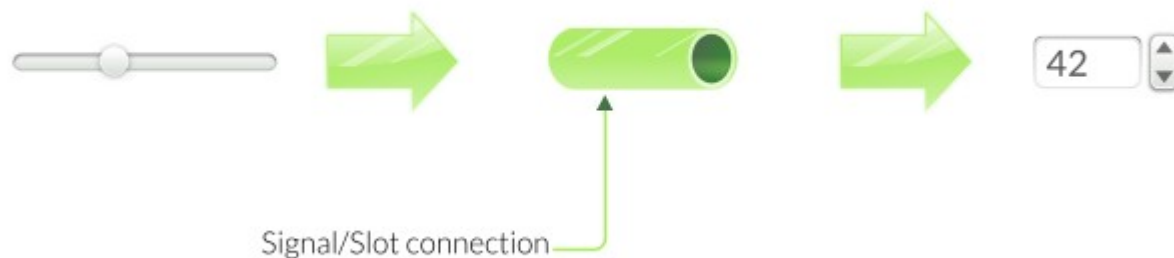
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Slot implemented



# Signals & Slots 4/8





# Signals & Slots 5/8

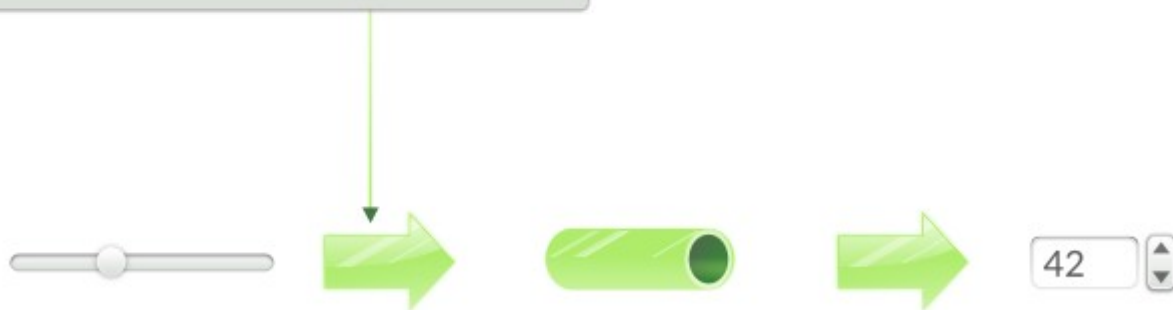


```
QObject::connect( slider, &QSlider::valueChanged,  
                 spinbox, &QSpinBox::setValue )
```



# Signals & Slots 6/8

```
void QSlider::mousePressEvent(...)  
{  
    ...  
    emit valueChanged( newValue );  
    ...  
}
```







# Signals & Slots 7/8

```
void QSpinBox::setValue( int value )  
{  
    ...  
    m_value = value;  
    ...  
}
```

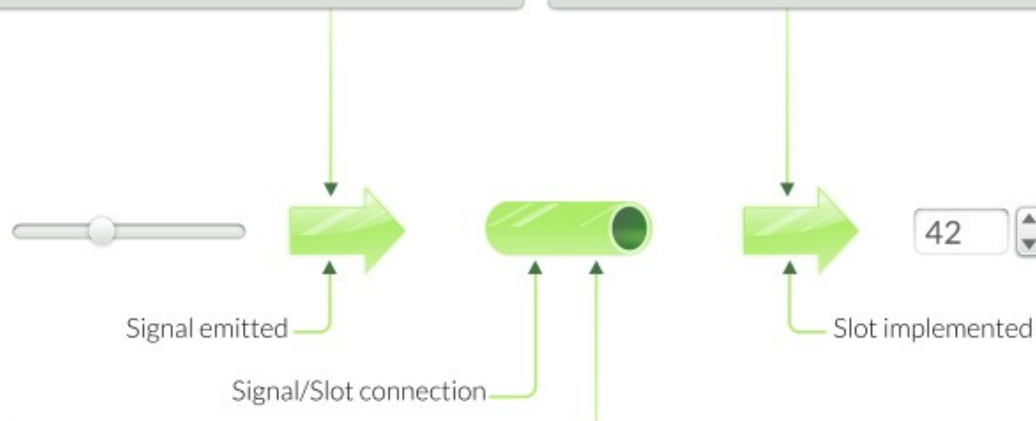




# Signals & Slots 8/8

```
void QSlider::mousePressEvent(...)  
{  
    ...  
    emit valueChanged( newValue );  
    ...  
}
```

```
void QSpinBox::setValue( int value )  
{  
    ...  
    m_value = value;  
    ...  
}
```



```
QObject::connect( slider, &QSlider::valueChanged,  
                 spinbox, &QSpinBox::setValue )
```



# About connections 1/4

Connection syntax (old school, the same as C++ Qt framework):

```
connect(w1, SIGNAL(signature), w2, SLOT(signature))
```

**w1**: source widget, sending a signal

**SIGNAL(signature)**: signal to be connected

**w2**: destination widget, which react to the signal with a slot

**SLOT(signature)**: method to be called when the signal is emitted

Example:

```
self.connect(aButton, SIGNAL('clicked()'), self, SLOT('close()'))
```

In this case, when the button aButton is clicked, the containing widget (self) will be closed



# About connections 2/4

*Rule for Signal/Slot Connection:*

**“Can ignore arguments, but not create values from nothing”**

Signal		Slot
rangeChanged(int,int)	ok	setRange(int,int)
rangeChanged(int,int)	ok	setValue(int)
rangeChanged(int,int)	ok	update()
valueChanged(int)	ok	setValue(int)
valueChanged(int)	ok	update()
valueChanged(int)	ok	setRange(int,int)
valueChanged(int)	ko	setValue(float)*
textChanged(QString)	ko	setValue(int)

\* Though not for Qt4 connection types



# About connections 3/4

Signal(s)	Connect to	Slot(s)
one	OK	many
many	OK	one
one	OK	another signal

- Signal to Signal connection

```
connect(btn, SIGNAL('clicked()'),  
        self, SIGNAL('emitOkSignal()'));
```

- **Not** allowed to name parameters

```
connect(mySlider, SIGNAL('valueChanged(int  
value)'))  
        self, SLOT('setValue( int newValue )'))
```



# About connections 4/4

Old connection syntax has a serious issue:

**if you don't write the signal signature exactly, signal will not be fired, but no warning or exception will be thrown.**

To avoid this behavior, there is another syntax for connections with PyQt:

**`sender.signalName.connect(receiver.slotName)`**

So the previous example:

```
self.connect(aButton, SIGNAL('clicked()'), self, SLOT('close()'))
```

Now become:

```
aButton.clicked.connect(self.close)
```



# Event processing

- Qt is an event-driven UI toolkit
- `QApplication::exec_()` runs the event loop

## 1) Generate Events

by input devices: keyboard, mouse, etc.  
by Qt itself (e.g. timers)

## 2) Queue Events

by event loop

## 3) Dispatch Events

by QApplication to receiver: QObject  
Key events sent to widget with focus  
Mouse events sent to widget under cursor

## 4) Handle Events

by QObject event handler methods



# Event handling

- `QObject::event(QEvent *event)`
  - Handles all events for this object
- Specialized event handlers for `QWidget` and `QQuickItem`:
  - `mousePressEvent()` for mouse clicks
  - `touchEvent()` for key presses
- Accepting an Event
  - `event->accept()` / `event->ignore()`
  - Accepts or ignores the event
  - Accepted is the default
- Event propagation
  - Happens if event is ignored
  - Might be propagated to parent widget



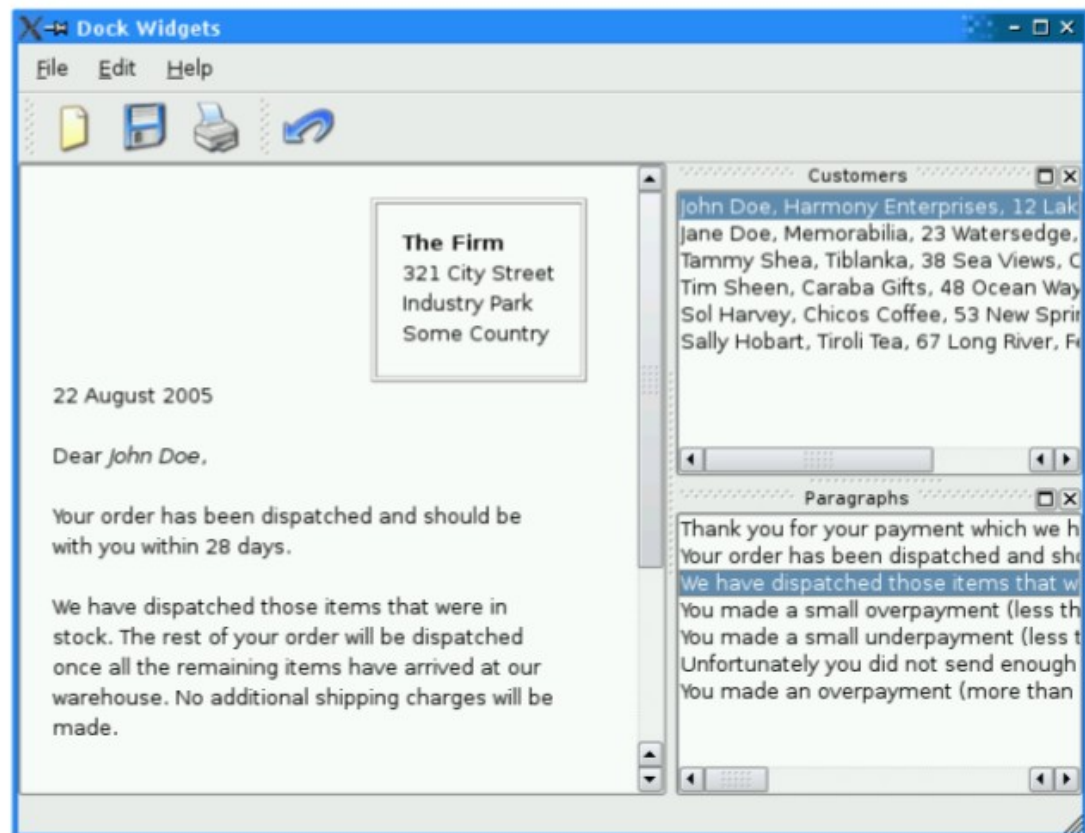


# Application creation



# Main Window

- QMainWindow: main application window
  - Has own layout
  - Central Widget
  - QMenuBar
  - QToolBar
  - QDockWidget
  - QStatusBar





# QAction 1/2

- Action is an abstract user interface command
- Emits signal triggered on execution
- Connected slot performs action
- Added to menus, toolbar, key shortcuts
- Each performs same way
- Regardless of user interface used



# QAction 2/2

To create an action, you can:

- Instantiate a QAction object directly
- Call addAction() on existing QMenu and QToolBar objects
- Then you can share it with other objects

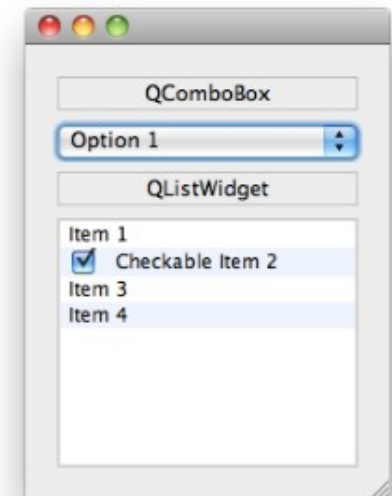
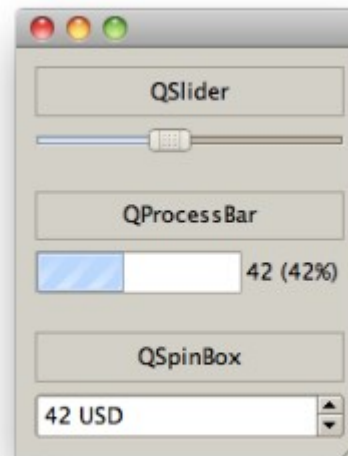
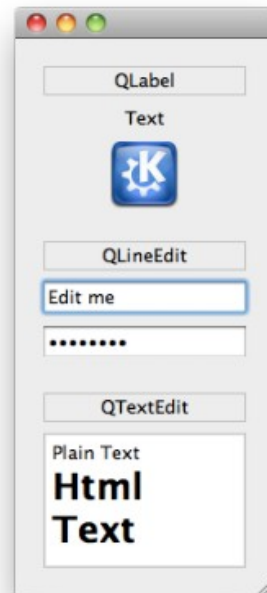
```
self.saveAction = QAction(QIcon(":/images/save.png"), "&Save...",
self)
self.saveAction.setShortcut("Ctrl+S")
self.saveAction.setStatusTip("Save the current form letter")
self.connect(self.saveAct, QtCore.SIGNAL("triggered()"), self.save)
...
self.fileMenu = self.menuBar().addMenu("&File")
self.fileMenu.addAction(self.saveAction)
...
self.fileToolBar = self.addToolBar("File")
self.fileToolBar.addAction(self.saveAct)
```



# Widgets



# Common widgets





# Common signals

Widget	Signals
<a href="#">QPushButton</a>	clicked()
<a href="#">QLineEdit</a>	editingFinished(), returnPressed(), textChanged(const QString&)
<a href="#">QComboBox</a>	activated(int), currentIndexChanged(int)
<a href="#">QCheckBox</a>	stateChanged(int)
<a href="#">QSpinBox</a>	valueChanged(int)
<a href="#">QSlider</a>	rangeChanged(int,int), valueChanged(int)



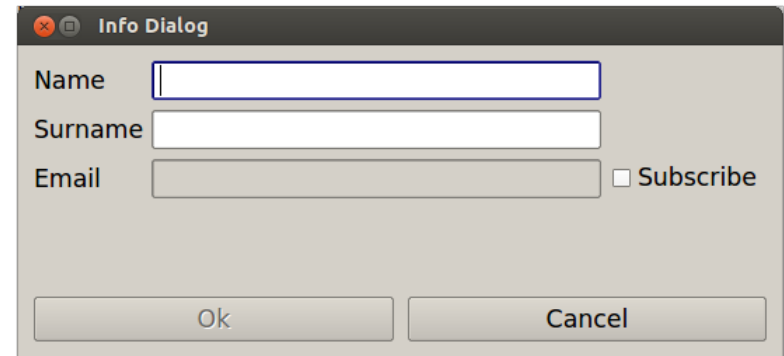
# Dialogs





# QDialog

- Base class of dialog window widgets
- General Dialogs can have 2 modes:
- **Modal dialog**
  - Remains in foreground, until closed
  - Blocks input to remaining application
  - Example: Configuration dialog
- **Non-Modal dialog**
  - Operates independently in application
  - Example: Find/Search dialog

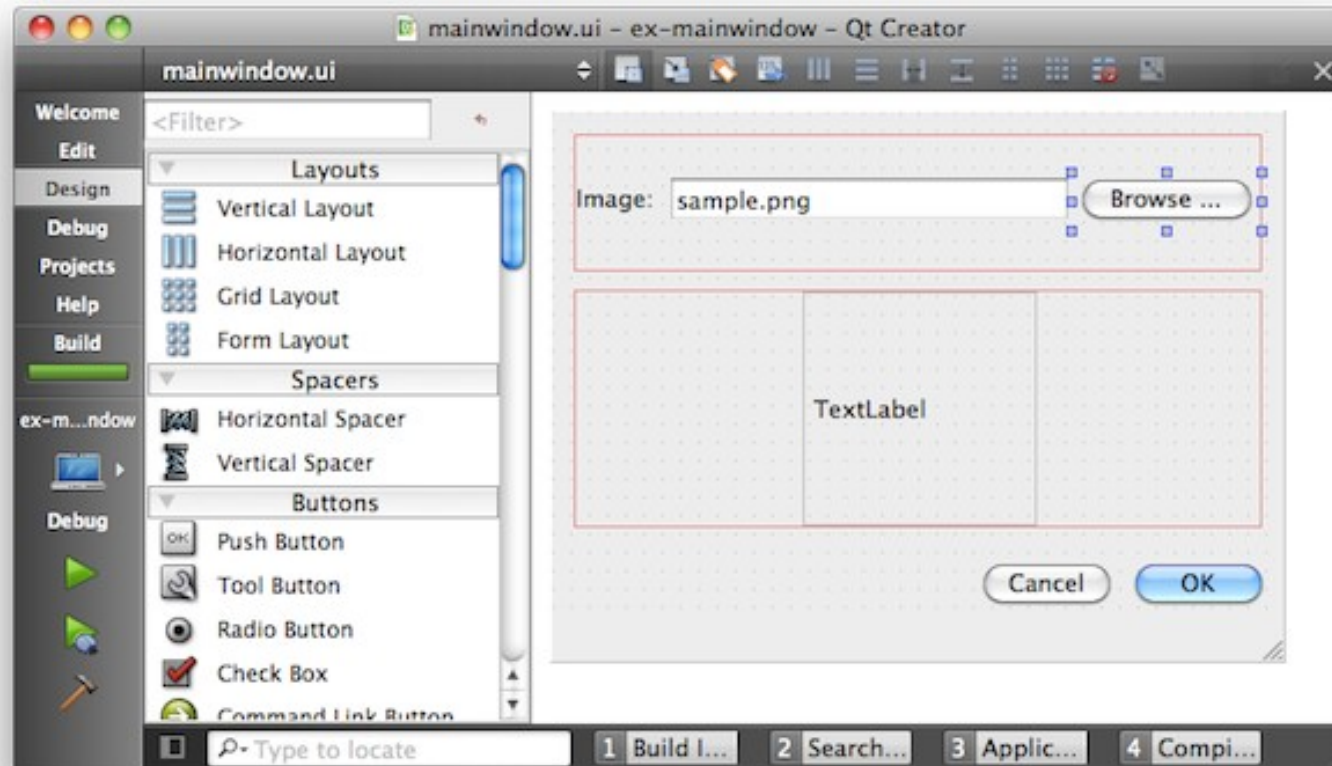




# Building User Interfaces



# Qt Designer





# Build GUI using QtDesigner 1/3

- Qt Designer uses **XML .ui files** to store designs and does not generate any code itself
- **pyuic4** takes a Qt4 user interface description file and compiles it to Python code
- The Python code is structured as a single class that is derived from the Python object type
- Class name is the name of the top level object set in Designer with **ui\_** prepended
- The class contains a method called **setupUi()**
  - This takes a single argument which is the widget in which the user interface is created



# Build GUI using QtDesigner 2/3

- 1) create your GUI (or use MyDialog.ui from pyuicExample)
- 2) generate the .py file

```
pyuic4 -o MyDialog_auto.py MyDialog.ui
```

- 3) use ui interface

```
from MyDialog_auto import Ui_Dialog

app = QApplication(sys.argv)
Dialog = QDialog()    ### create new dialog
ui = Ui_Dialog()     ### create a new instance of your gui
ui.setupUi(Dialog)   ### apply the gui to the created dialog

Dialog.show()
sys.exit(app.exec_())
```



# Build GUI using QtDesigner 3/3

> **pyuic4 -h**

Usage: pyuic4 [options] <ui-file>

Options:

<code>--version</code>	show program's version number and exit
<code>-h, --help</code>	show this help message and exit
<code>-p, --preview</code>	show a preview of the UI instead of generating code
<code>-o FILE, --output=FILE</code>	write generated code to FILE instead of stdout
<code>-x, --execute</code>	<b>generate extra code to test and display the class</b>
<code>-d, --debug</code>	show debug output
<code>-i N, --indent=N</code>	set indent width to N spaces, tab if N is 0 (default: 4)
<code>-w, --pyqt3-wrapper</code>	generate a PyQt v3 style wrapper

Code generation options:

<code>--from-imports</code>	generate imports relative to '.'
-----------------------------	----------------------------------

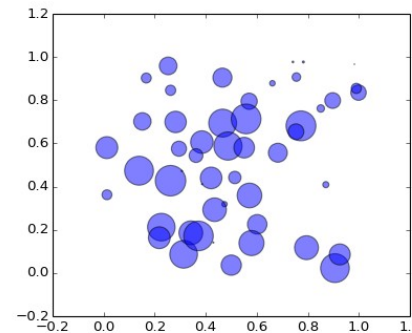
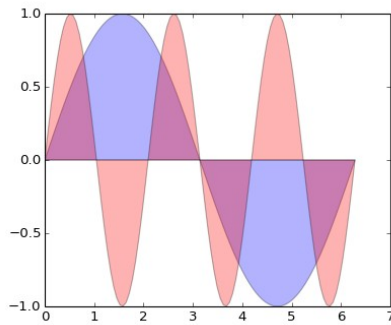
With `-x` option the generated Python class should be executed standalone to be displayed



# Matplotlib and Qt 1/6

**Matplotlib** is a Python 2D interactive plotting library

<http://matplotlib.org/>



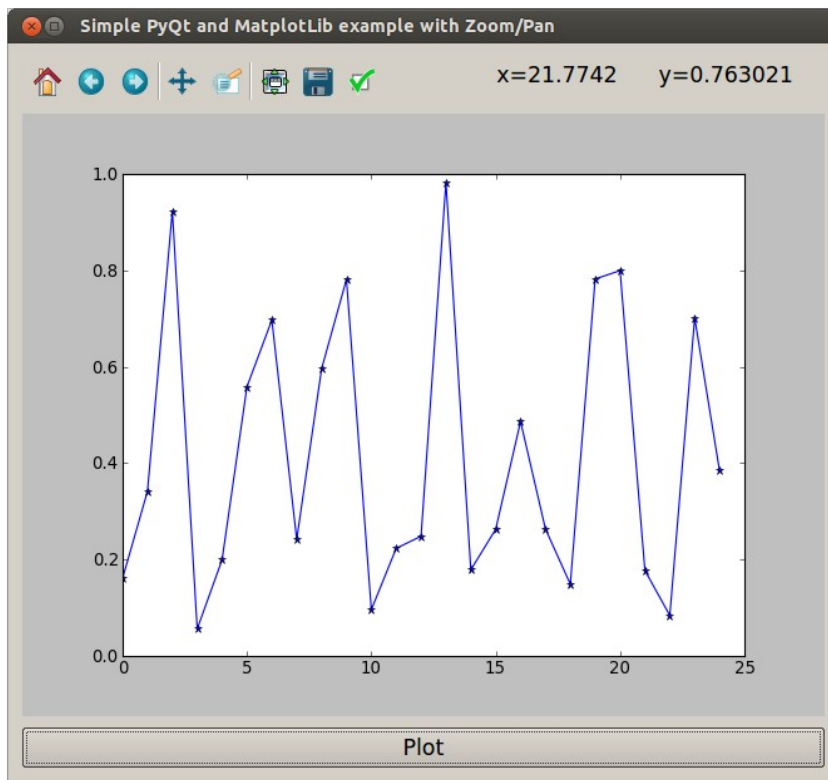
We will see how to:

- ▮ Embed a Matplotlib Figure into a Qt window
- ▮ Embed a Navigation Toolbar



# Matplotlib and Qt 2/6

Open `MatplotlibExample/matplotlibExample.py`



App features:

- generate a set of 25 points and plot it pressing “Plot” button
- show navigation toolbar for zooming/panning





# Matplotlib and Qt 3/6

```
#import modules from Matplotlib
from matplotlib.backends.backend_qt4agg import FigureCanvasQTAgg as FigureCanvas
from matplotlib.backends.backend_qt4agg import NavigationToolbar2QTAgg as NavigationToolbar
import matplotlib.pyplot as plt

#import random module to generate set
import random
```

**Figure** Matplotlib object: this is the backend-independent representation of our plot

Import from the **matplotlib.backends.backend\_qt4agg** the module **FigureCanvasQTAgg** class, which is the backend-dependent figure canvas. It contains the backend-specific knowledge to render the Figure we've drawn.

Note that **FigureCanvasQTAgg**, other than being a Matplotlib class, is also a Qwidget, the base class of all user interface objects. So this means we can treat FigureCanvasQTAgg like a pure Qt widget Object. NavigationToolbar2QTAgg also inherits from QWidget, so it can be used as Qt objects in a Qapplication.

References:

[http://matplotlib.org/api/backend\\_qt4agg\\_api.html](http://matplotlib.org/api/backend_qt4agg_api.html)

[http://matplotlib.org/api/pyplot\\_api.html](http://matplotlib.org/api/pyplot_api.html)

[http://matplotlib.org/api/figure\\_api.html#module-matplotlib.figure](http://matplotlib.org/api/figure_api.html#module-matplotlib.figure)

<https://docs.python.org/2/library/random.html>



# Matplotlib and Qt 4/6

```
class Window(QtGui.QDialog):
    def __init__(self, parent=None):
        super(Window, self).__init__(parent)

        #init figure and canvas
        self.figure = plt.figure()
        self.canvas = FigureCanvas(self.figure)

        #init nav toolbar
        self.toolbar = NavigationToolbar(self.canvas, self)

        # Add plot button
        self.button = QtGui.QPushButton('Plot')

        # connect button to custom slot (see later)
        self.button.clicked.connect(self.plot)

        # set the layout
        layout = QtGui.QVBoxLayout()
        layout.addWidget(self.toolbar)
        layout.addWidget(self.canvas)
        layout.addWidget(self.button)
        self.setLayout(layout)
```



# Matplotlib and Qt 5/6

```
### our custom slot
def plot(self):
    # random data
    data = [random.random() for i in range(25)]

    # create an axis
    ax = self.figure.add_subplot(1,1,1)

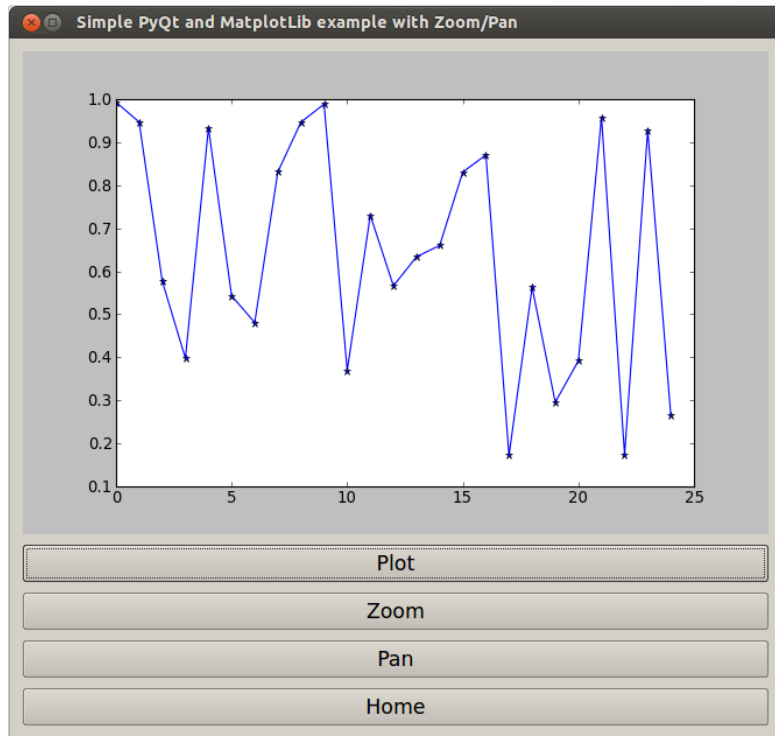
    # discards the old graph
    ax.hold(False)

    # plot data
    ax.plot(data, '*-')

    # refresh canvas
    self.canvas.draw()
```



# Matplotlib and Qt 6/6



## Exercise

Modify the previous example adding custom buttons which will act as the navigation toolbar:

Plot > plot random dataset

Zoom > activate zoom on canvas

Pan > activate pan on canvas

Home > reset view

Hint #1: you will have to connect your buttons to navigation toolbar `zoom()`, `pan()` and `home()` methods

Hint #2: open

`MatplotlibExample/matplotlibExampleCustom.py`



# Resources

*[PDF] PyQt whitepaper*

<http://www.riverbankcomputing.co.uk/static/Docs/PyQt4/pyqt-whitepaper-a4.pdf>

*[BOOK] Rapid GUI Programming with Python and Qt*

[http://qt-project.org/books/view/rapid\\_gui\\_programming\\_with\\_python\\_and\\_qt](http://qt-project.org/books/view/rapid_gui_programming_with_python_and_qt)