Object Oriented Programming - Lecture 11

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Content

- Callback functions
- Qt signal and slots
- Meta-information about QObjects
- Qt UI elements (cont'd)

Callbacks I

- When dealing with graphical user interfaces we often want to be notified about the user interface elements that have been modified (by the user).
  - we want to perform an action when the user presses a button.
  - when a value is chosen in a combobox, a list should be populated with different values etc.
- In many toolkits this is achieved using callbacks.
- A **callback** is any executable code (function) that is passed as an argument to other code (function); that other code is expected to call back (i.e. execute) the argument function when appropriate.

Callbacks II

- A callback is a function that is called by another function, when an event happens.
- In order to be notified by a processing function that an event occurred, we pass a pointer to another function (**the callback**) to the processing function.
- The processing function then calls the callback when appropriate (when the event occurs).
- We already used callbacks: for example, when sorting an array using the qsort() function, we passed a pointer to the comparison function to qsort().

Callbacks III

Callback example

Progress notification

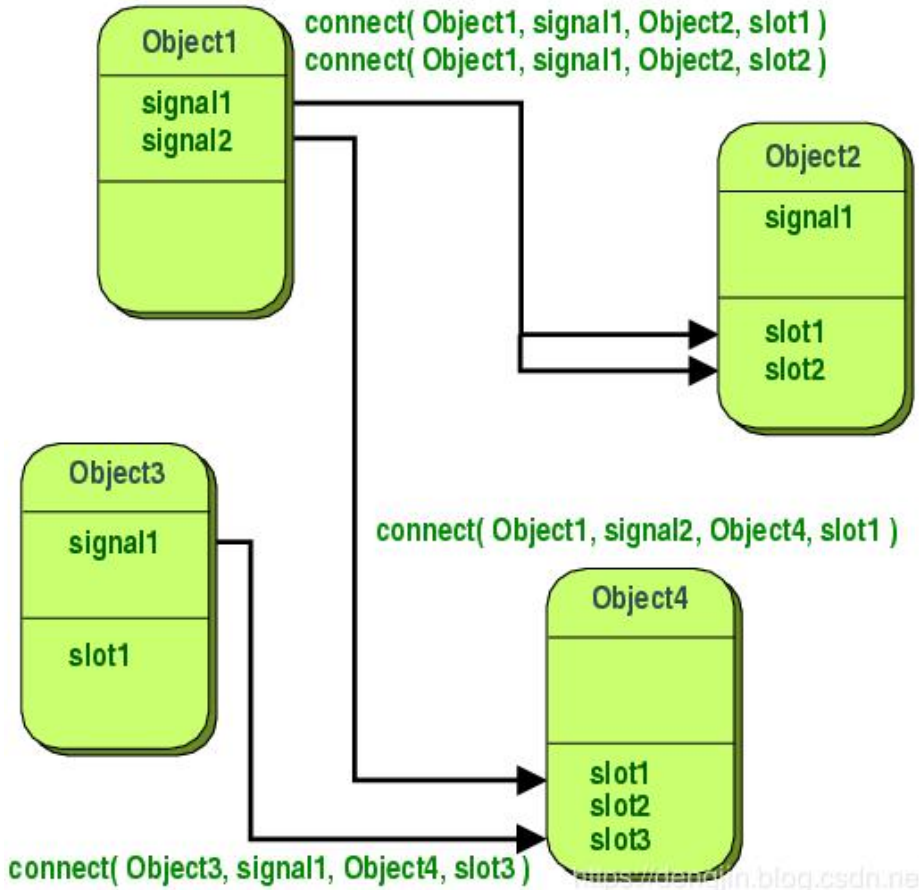
- Callback disadvantages:
  - if there are several notifications needed, we either need separate callback functions, or we could use generic parameters (void*), which cannot be verified at compile-time.
  - the processing function is coupled to the callback function (it needs to know its signature, its parameters).

Signals and slots in Qt I

- Qt uses an alternative to callbacks: the **signals and slots mechanism**.
  - This is a central feature of Qt and probably the part that differs most from other frameworks.
- A **signal** is emitted when a particular **event occurs**.
  - Qt's widgets have many predefined signals, but signals can also be added to custom widgets and classes.
- A **slot** is a function that **is called in response to a particular signal**.
  - Qt's widgets have many predefined slots, but it is common practice to subclass widgets and add your own slots so that you can handle the signals that you are interested in.

Signals and slots in Qt II

- The signals and slots mechanism is **type safe**: the signature of a signal must match the signature of the receiving slot.
- Only classes that inherit from QObject or one of its subclasses (e.g., QWidget) can contain signals and slots.
- Signals and slots are **loosely coupled**: A class which emits a signal neither knows nor cares which slots receive the signal.



Signals and slots III

- Slots can be used for receiving signals, but they are also normal member functions.
- A slot does not know if it has any signals connected to it.
- Multiple signals can be connected to a single slot, and a signal can be connected to as many slots as needed.
- It is even possible to connect a signal directly to another signal. $\rightarrow$ the second signal is emitted immediately whenever the first is emitted.

Signals

- A signal is emitted when a particular event occurs.
- Signal can never have return types (i.e. they always return void).
- If several slots are connected to the same signal, the slots will be executed one after the other, in the order they have been connected, when the signal is emitted.
- When a signal is emitted, the slots connected to it are usually executed immediately (except for queued connections), just like a normal function call.
- Execution of the code following the emit statement will occur once all slots have returned.
- Signals are automatically generated by the *moc* and must not be implemented in the .cpp file.

Slots

- A slot is called when a signal connected to it is emitted.
- Slots are normal C++ functions and can be called normally; their only special feature is that signals can be connected to them.
- Using a signal-slot connection, slots can be invoked by any component.
  - A signal emitted from an instance of class A can cause a private slot to be invoked in an instance of class B, even if A and B are unrelated.

Meta Object Compiler I - moc

- Qt's meta-object system provides the signals and slots mechanism for inter-object communication, run-time type information, and the dynamic property system.
- The meta-object system is based on three things:
  - The QObject class: base class for objects that can take advantage of the meta-object system.
  - The Q_OBJECT macro inside the private section of the class declaration is used to enable meta-object features (signals, slots, runtype info.)
  - the Meta-Object Compiler (*moc*)
- *moc* is the program that handles Qt's C++ extensions (signals, slots, runtime info.).
- It is a code generator: it parses the header files and generates an additional C++ file that is compiled with the rest of the program.

Meta Object Compiler II - moc

- The meta-object compiler takes all classes starting with the Q_OBJECT macro and generates a moc *.cpp C++ source file.
- This file contains information about the class being "moc-ed" such as class name, inheritance tree and also the names and pointers to the signal and slot members.
- This means that emitting a signal is actually calling a function generated by the *moc*.
- Macros used by the *moc*:
  - signals
  - emit
  - slots
  - SIGNAL
  - SLOT

QtMetaObject - introspection

- The QtMetaObject class offers meta-information about Qt objects
  - **className()**returns the name of a class.
  - **superClass()** returns the superclass' meta-object.
  - **method()** and **methodCount()** provide information about a class' meta-methods (signals, slots and other invokable member functions).
  - **enumerator()** and **enumeratorCount()** and provide information about a class' enumerators.
  - **propertyCount()** and **property()** provide information about a class' properties.
  - **constructor()** and **constructorCount()** provide information about a class' meta-constructors.

Demo

Introspection example

Custom signals and slots

- All classes that contain signals or slots must mention Q_OBJECT at the top of their (private) declaration.
- They must also derive (directly or indirectly) from QObject.

Custom signals

- Custom signals can be defined using the signals macro.

```
signals:
    void sizeChanged();
    void elementRemoved(std::string id);
```

- Signals can be emitted by an object when its internal state has changed in some way that might be interesting to another object.
- The emit macro is used to emit signals.

```
emit sizeChanged();
```

- Signals are public access functions and can be emitted from anywhere, but it is recommended to only emit them from the class that defines the signal and its subclasses.

Custom slots

- Custom slots are declared using the slots keyword.
- slots is actually an empty macro needed by the *moc* tool to generate meta-information about the available slots.
- Slots are normal C++ functions and can be called normally
- Their only special feature is that signals can be connected to them.

```
slots:
    void onSizeChanged();
    void onElementRemoved(std::string id);
```

Connecting signals to slots

- There are two alternative ways of connecting signals to slots:

```
// first version: using the SIGNAL and SLOT macro
QLabel *label = new QLabel;
QLineEdit *lineEdit = new QLineEdit;
QObject::connect(lineEdit, SIGNAL(textChanged(QString)),
                 label,  SLOT(setText(QString)));

// newer version
QLabel *label = new QLabel;
QLineEdit *lineEdit = new QLineEdit;
QObject::connect(lineEdit, &QLineEdit::textChanged,
                 label,  &QLabel::setText);
```

- The signal and slot mechanism can also be used from QtDesigner: https://doc.qt.io/qt-5/designer-connection-mode.html.

Signals and slots disadvantages

- The main advantages of signal and slots is that they provide great flexibility and simplicity.
- However, compared to callbacks, signals and slots are slightly slower, although the difference for real applications is insignificant.
- Usually emitting a signal that is connected to some slots, is about 10 times slower than calling the receivers directly, with non-virtual function calls.
- The meta object system needs to locate the connection object, to safely iterate over all connections, and to marshall any parameters in a generic fashion.
- However, this overhead is much less than for other operations, like new or delete.

QDebug

- The QDebug class provides an output stream for debugging information.
- QDebug is used whenever the developer needs to write out debugging or tracing information to a *device, file, string* or *console*.
- In the most common usage, you should call the qDebug() function to obtain a default QDebug object to use for writing debugging information.
- In Visual Studio, the messages printed with qDebug() will be displayed in the *Output* window.
- It is defined in header <QDebug>.

QString I

- The QString class provides a Unicode character string.
- It is used in Qt to store strings.
- The class has an constructor that accepts a const char*: QString(const char *str), so functions that have a QString as parameter will accept also a const char*.
- To convert between a QString and a std::string you can use the toStdString() and QString::fromStdString(std::string) methods;
- The QString class also have methods to convert between a QString and a number and viceversa: toInt() and QString::number(int) methods;

QString II

- Other useful methods from QString:
  - contains() check whether a QString contains a particular character or substring;
  - startsWith() or endsWith(): check if a QString starts or ends with a particular substring.
  - count(): determines how many times a particular character or substring occurs in the string.
  - QString can be compared using overloaded operators such as operator<(), operator<=(), operator==(), operator>=(), and so on. *Note that the comparison is based exclusively on the numeric Unicode values of the characters.*

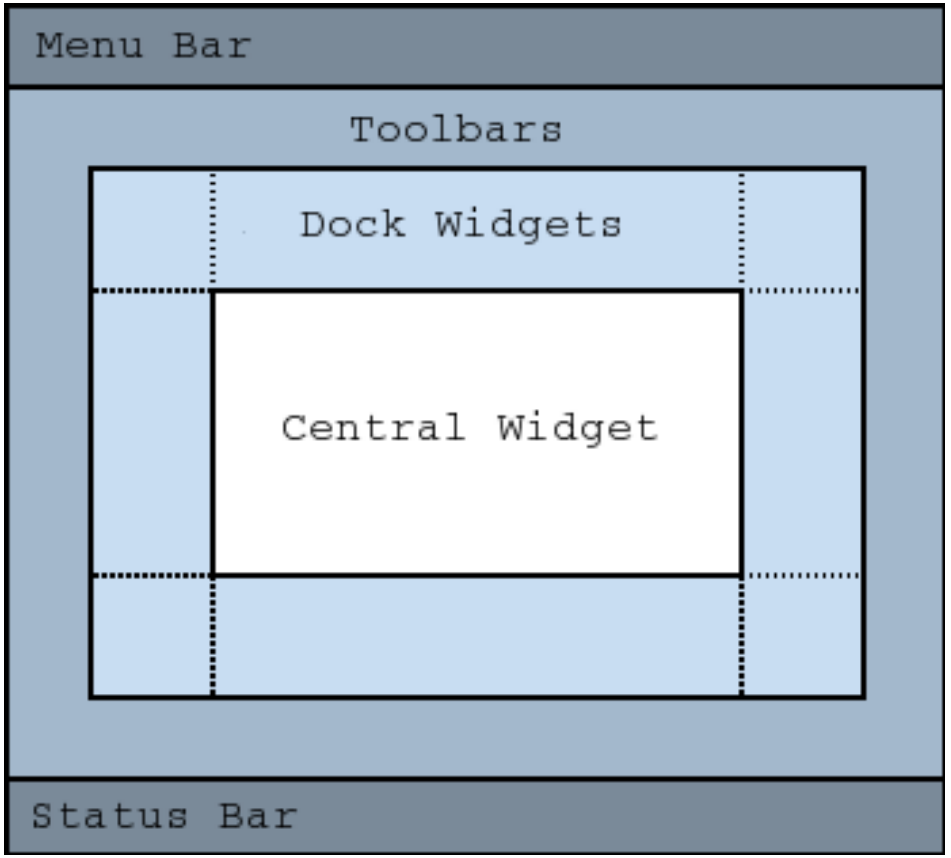
QMessageBox

- A message box QMessageBox is a model window that displays a text to inform user of a situation or to ask the user a question.
- It can display text, an item and standard buttons (*OK*, *Cancel*, *Open*, *Close*, *Save*, *Discard* etc.) for user response.
- QMessageBox supports four predefined message severity levels, or message types, which really only differ in the predefined icon they each show:

	Question	For asking a question during normal operations.
	Information	For reporting information about normal operations.
	Warning	For reporting non-critical errors.
	Critical	For reporting critical errors.

QMainWindow I

- QMainWindow provides a main application window.
- QMainWindow has its own layout to which you can add:
  - a menu bar (at the top): QMenuBar
  - several tool bars: QToolBar
  - a status bar (at the bottom): QStatusBar
  - The layout has a center area that can be occupied by any kind of widget.



QMainWindow II

- QMainWindow provides the function menuBar(), which allows adding QMenus to the menu bar and adding QActions to the pop-up menus.
- QAction can be used for common commands can be invoked via menus, toolbar buttons, and keyboard shortcuts.

QMainWindow III

- QToolBar provides a movable panel that contains a set of controls.
- Toolbar buttons are added by adding actions, using the function addAction.

QPainter I

- The QPainter class performs low-level painting on widgets or other paint devices (classes that inherit form QPaintDevice.
- It can draw everything from simple lines to complex shapes like pies and chords. It can also draw aligned text and pixmaps.
- QPainter provides functions to draw most primitives: drawPoint(), drawPoints(), drawLine(), drawRect(), drawRoundedRect(), drawEllipse(), drawArc(), drawPie(), drawChord(), drawPolyline() etc.
- The QPainterPath is an object composed of building blocks such as rectangles, ellipses, lines.

QPainter II

- There are several settings that you can customize to make QPainter draw according to your preferences:
  - using a QBrush - you can define the color or pattern that is used for filling shapes.
  - using a QPen - you can define the color or stipple that is used for drawing lines or boundaries.
- The paintEvent method (of the QWidget class) is invoked when the QWidget needs to repaint all or part of the widget.
- **!!** When the paintdevice is a widget, QPainter can only be used inside a paintEvent() function or in a function called by paintEvent() **!!**

Demo

Painting example

Summary

- Signals and slots are used for communication between objects.
- A signal is emitted when a particular event occurs.
- A slot is a function called in response to a particular signal.
- Signals and slots must be connected.