

Qt Signals and Slots

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Overview

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- When we change one widget, we often want another widget to be notified. E.g.:
 - when the close button is pressed on a main window in an application, all application related windows should be closed;
 - when a value is chosen in a combobox, a list should be populated with different values.
- In other toolkits, this kind of communication is achieved using callbacks.

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- A callback is function that is called by another function, when an event happens.
- If you want a processing function to notify you about some event you pass a pointer to another function (the callback) to the processing function.
- The processing function then calls the callback when appropriate.
- E.g.
 - Comparison function passed to a sorting algorithm.
 - A progress bar object, which could be used by any client.

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Example - progress bar

- The prototype of the callback function is defined by the developer of the progress bar.

```
//callback function prototype
typedef void(*ProgressListener)(int percent);

//function that notifies progress using callback
void someComputation(ProgressListener callback)
{
    for (int i = 0; i < 100; i++)
    {
        cout << "Doing some computation\n";
        callback(i); //notification after each
                     step
    }
}
```

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```
#include <functional>

//function that notifies progress using callback
void someComputation(std::function<void(int)>
    callback)
{
    for (int i = 0; i < 100; i++)
    {
        //do stuff
        cout << "Doing some computation\n";
        callback(i); // notification after each
                     step
    }
}
```

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- The client code (which needs the notifications) will have to define a function with that specific prototype.

```
void onProgress(int percent)
{
    std::cout << "progress:" << percent;
}

int main()
{
    someComputation(onProgress);
}
```

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- Callbacks in c++ have two fundamental 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).

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- Qt signals and slots are an alternative to the callback mechanism.
- They are used for communication between objects.
- The signals and slots mechanism is a central feature of Qt.

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- A **signal** is emitted when a particular event occurs (e.g. a button is clicked).
- Qt widgets have many pre-defined signals which are emitted to indicate that a user action or a change of state has occurred.
- A **slot** is a function that is called in response to a particular signal.
- A signal can be connected to a function (called a slot), so that when the signal is emitted, the slot is automatically executed.

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- The signature of a signal must match the signature of the receiving slot (in fact, a slot may have a shorter signature than the signal it receives because it can ignore extra arguments) ⇒ **the signals and slots mechanism is type safe.**
- Slots can be used for receiving signals, but they are also normal member functions.
- Just as an object does not know if anything receives its signals, a slot does not know if it has any signals connected to it ⇒ truly independent components can be created with Qt and there is a **loose coupling between signals and slots.**

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- You can connect as many signals as you want to a single slot, and a signal can be connected to as many slots as you need.
- Qt widgets have many predefined signals, but we can subclass widgets to add new signals to them.
- Qt widgets have many pre-defined slots.
- It is common practice to subclass widgets and add your user-defined slots that can handle the signals.

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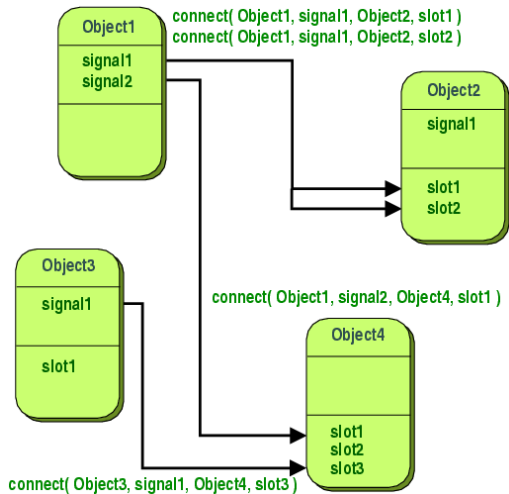


Figure source: <https://doc.qt.io/qt-6/signalsandslots.html>

Connecting signals and slots I

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- 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.
- Several slots can be connected to one signal, the slots will be executed one after the other, in the order they have been connected, when the signal is emitted.

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- To connect a signal and a slot we use the function `QObject::connect` and (optionally) the macros `SIGNAL` and `SLOT`.

```
QPushButton *closeButton = new QPushButton("Close");  
// Qt5  
QObject::connect(closeButton, &QPushButton::clicked,  
                 QApplication::instance(), &QApplication::quit);  
// older Qt versions  
QObject::connect(closeButton, SIGNAL(clicked()),  
                 QApplication::instance(), SLOT(quit()));
```

Spin and slider example I

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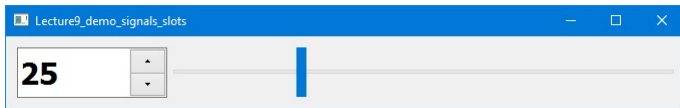
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If the the user changes the value in the Spin Box:

- The spinbox will **emit the signal** `valueChanged(int)` with an int argument, the current value of the spinner.
- Because the spinner and slider are connected, the `setValue(int)` method of the slider will be invoked. The argument from the `valueChanged` method (the current value of the spinner) will be passed to the `setValue` method of the slider.

Spin and slider example II

- The slider updates itself to reflect the new value, and emits a `valueChanged` signal because its own value has changed.
- Because the slider is also connected with the spinner, the `setValue` slot of the spinner is invoked, in response to the slider's signal.
- The `setValue` of the spinner will not emit any signal because the current value is the same as the value provided in the `setValue` (prevents infinite loop).

DEMO

Simple example of connecting signals and slots (*Lecture10_demo_spin_slider*).

Subclassing QWidget

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- Create a separate class for the GUI that you are designing.
- This class must inherit from `QWidget`.
- Make it an independent, self-contained component, with its own signals and slots.

The meta-object system

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- Qt introduces a mechanism called the **meta-object system** which provides two key services:
 - signals and slots;
 - introspection
 - the ability to introspect objects at runtime;
 - the the methods and properties of an object can be listed at runtime;
 - is necessary for implementing signals and slots;
 - allows application programmers to obtain "meta-information" about [QObject](#) subclasses at run-time, including the list of signals and slots supported by the object and its class name.

The meta-object compiler I

- The meta-object compiler (MOC) is the tool that provides introspection support.
- It is a code generator - parses the header files and generates an additional C++ file that is compiled with the rest of the program.
- 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.

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- This means that emitting a signal is actually calling a function generated by the MOC.
- Macros used by the MOC:
 - `signals`
 - `slots`
 - `Q_OBJECT`
 - `emit`
 - `SIGNAL`
 - `SLOT`
- "We strongly recommend that all subclasses of `QObject` use the `Q_OBJECT` macro regardless of whether or not they actually use signals, slots, and properties." (Qt documentation: <https://doc.qt.io/qt-6/metaobjects.html>)

The meta-object compiler III

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DEMO

Simple example of introspection (*Lecture10_introspection*).

Custom slots I

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- The syntax in Qt6 allows us to connect signals to any member function of QObject, not only slots.
- If connections are made via the **SIGNAL** and **SLOT** macros, then slots have to be declared using the **slots** keyword.
- A slot is just a regular method and the compiler will handle it as any other function.
- 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.

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- Custom signals can be defined using the `signals` macro.

```
signals :  
    void genesUpdatedSignal();  
    void addGeneSignal(const std::string&  
        geneName, const std::string&  
        organismName, const std::string&  
        sequence);
```

- Signals can be emitted by an object when its internal state has changed in some way that might be interesting to another object.
- They can never have return types (use `void`).

Custom signals II

- The `emit` macro is used to emit signals.

```
void GenesGUI::deleteGene()  
{  
    // ...  
    // emit the signal: the genes were updated  
    emit genesUpdatedSignal();  
}
```

- 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.
- When a signal is emitted, the slots connected to it are usually executed immediately, just like a normal function call.

Custom signals III

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- Execution of the code following the `emit` statement will occur once all slots have returned.
- If several slots are connected to one signal, the slots will be executed one after the other, in the order they have been connected.

Example

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Gene manager (*Lecture10_genes*).

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- Qt Designer is the Qt tool for designing and building GUIs.
- Windows and dialogs can be designed in a what-you-see-is-what-you-get manner.
- Objects can be dragged from the widget box and dropped on the form.
- Object properties can be modified interactively.

Qt Designer II

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- Using the Qt Designer can be faster than hand-coding the interface.
- One can experiment with different designs quickly.
- A **.ui** file is created, representing the widget tree of the form in XML format. The *User Interface Compiler (uic)* can then be used to create a corresponding C++ header file.

DEMO

Qt Designer (*Lecture10_qt_designer*).

When should we write code programatically?

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- When the elements in the dialog must change dynamically.
- When we want to use custom widgets.

How?

- 1 Create a new class, by inheriting from `QWidget`.
- 2 Implement the GUI.
- 3 Show the newly created widget.

QMainWindow

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- A main window provides a framework for building an application's user interface.
- QMainWindow has its own layout to which you can add:
 - A menu bar (on the top): `QMenuBar`;
 - Toolbars: `QToolBar`;
 - A central widget: this will typically be a `QTextEdit` or a `QGraphicsView`;
 - A status bar (on the bottom) : `QStatusBar`.

Using the menu bar

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- `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.

```
QMenu* fileMenu = this->menuBar()->addMenu("&File");  
QAction *openAction = new QAction("&Open", this);  
fileMenu->addAction(openAction);
```


Using the tool bar

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

```
QToolBar* fileToolBar = addToolBar("&File");  
fileToolBar->addAction(openAction);  
fileToolBar->addAction(saveAction);
```

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Notepad example (*Lecture10_notepad*).

QPainter I

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Other useful
Qt classes

- **QPainter** is used for low-level painting on custom defined widgets.
- It can draw simple and complex shapes (from lines to pies).
- The **QPen** object, which defines how a painter should draw lines and outlines of shapes.
- The **QBrush** defines the fill pattern of shapes drawn by a QPainter.
- The **QPainterPath** is an object composed of building blocks such as rectangles, ellipses, lines.

QPainter II

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- The `paintEvent` method (of the `QWidget` class) is invoked when the `QWidget` needs to repaint all or part of the widget.
- The `keyPressEvent` method is invoked when a key is pressed (**only if** the widget has the focus).
- The `mousePressEvent` method is invoked when a mouse key is pressed.

DEMO

Drawing example (*Lecture10 - Drawing*).

QString

- Unicode character string.
- The functions that have a `QString` as parameter will accept a `const char*`.
- There are methods to convert a `QString` in an `std::string` and viceversa.

```
QString s = "145";  
std::string ss = s.toStdString();  
QString s2 = QString::fromStdString(ss);
```

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- There are methods to convert a `QString` in a number and viceversa.

```
QString s = "145";  
int a = s.toInt();  
double d = 3.8;  
QString s3 = QString::number(d);
```

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QVector

- This is a template class that provides a dynamic array.
- It stores its items in adjacent memory locations and provides fast index-based access.
- It offers operations similar to the STL vector.
- It can be converted to an STL vector and viceversa (function `toStdVector`, `fromStdVector`).

QMessageBox

- Provides a modal dialog to show information.
- It can display text, an item and standard buttons (OK, Cancel, Open, Close, Save, Discard, etc.) for user response.
- There are 4 message types, which really only differ in the predefined icon they each show:
 - Question
 - Information
 - Warning
 - Critical

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```
QMessageBox::information(this, "Info", "Selection  
    changed");  
// ...  
int ret = QMessageBox::warning(this, "My Application  
    ", "The document has been modified.Do you want  
    to save your changes?", QMessageBox::Save |  
    QMessageBox::Discard | QMessageBox::Cancel ,  
    QMessageBox::Save);  
if (ret == QMessageBox::Save) {  
    //do save  
}
```

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QDebug

- Provides an output stream for debugging information.
- It is useful to call the `QDebug()` function to obtain a default QDebug object to use for writing debugging information.
- In VS, the message will be displayed in the "Output" window.

```
QDebug() << "Here is a message for debug.";
```

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- 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.