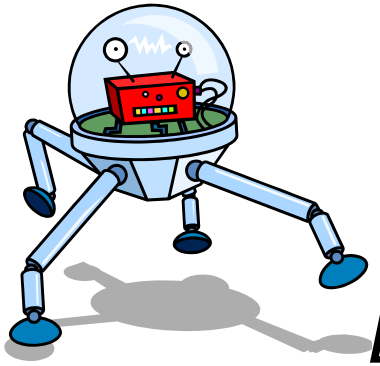
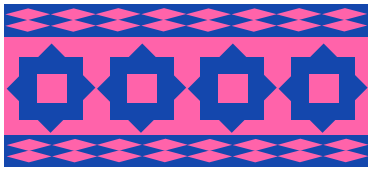
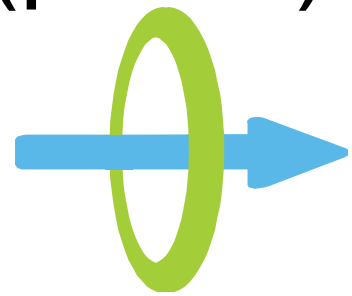
Caltech/LEAD Summer 2012 Computer Science

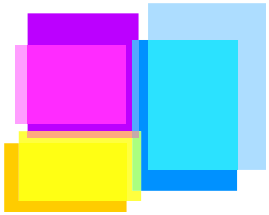


Lecture 12: July 19, 2012

Graphics and Graphical User Interfaces (part 2)







This lecture

- Event handling
  - `bind`
  - key presses, mouse clicks
  - using events
- Graphical object "handles"
  - A way to control objects already on the canvas
- Global variables

mainloop

- Last time we had:

```
from Tkinter import *
root = Tk()
root.geometry('800x600')
c = Canvas(root, width=800, height=600)
c.pack()
r = c.create_rectangle(0, 0, 50, 50,
          fill='red', outline='red')
root.mainloop()
```

mainloop

- We added the

```
root.mainloop()
```

- line in place of the `raw_input` line
- The drawing doesn't change
- Now, the only way to exit the program is to close the window or to quit Python
- So far, haven't added any code to handle any events

Event 1: q for quit

- Let's add an event so that pressing the `q` key on the canvas quits the application
- We will add just one line before the `mainloop` line:

```
root.bind('<q>', quit)
```

- Let's look at this line in detail

Event 1: q for quit

```
root.bind('<q>', quit)
```

- This says:
- The graphical object that will handle the event is the `root` object
- The event to be handled is when the user presses the `q` key on the keyboard
  - `Tkinter` represents this as the string `'<q>'`
- When the `q` key is pressed, the built-in `quit` function will be executed
  - This causes Python to exit immediately

Event 1: q for quit

```
root.bind('<q>', quit)
```

- We say that this method call *binds* the event (pressing the `q` key on the keyboard) to the function `quit` (which handles the event)

Event 1: `q` for quit

- This works, but there is one odd thing
- When `q` is pressed, the program exits
  - but before it does, it prints out something like:

```
<Tkinter.Event instance at 0x776058>
```

- What does this mean?

Event 1: q for quit

- The `quit` function usually gets no arguments
- If it gets an integer argument, it passes it to the operating system
  - (the reason isn't important)
- If it gets a non-integer argument, it prints it and then exits
- Somehow, here it got an argument of type `Tkinter.Event`

Event 1: `q` for quit

- What happened:
- When the `q` key on the keyboard was pressed
  1. `Tkinter` created a `Tkinter.Event` object
  2. `Tkinter`'s event loop (`mainloop`) checked to see if the `q` key was bound to any function
  3. It found that `q` was bound to the `quit` function
  4. It called `quit` with the `Tkinter.Event` object as its argument
  5. `quit` printed the event and then made Python exit

Event 1: q for quit

- Another weird thing...
- Look at the line:

```
root.bind('<q>', quit)
```

- `quit` is the name of a Python function
- The `bind` method of the `root` object can take a *function* as an argument!
- Python allows functions to be treated as data
  - functions are "first-class"

Callbacks

```
root.bind('<q>', quit)
```

- Functions like `quit` which are arguments to the `bind` method are called *event handlers*
  - because they "handle events"
- Also often called *callbacks* or *callback functions*
- The root object stores them and "calls them back" whenever the event happens
- When it does this, it passes the event as the only argument to the function

Callbacks

- We would like for the program to exit when the `q` key is pressed, without printing anything
- We can do this by defining our own callback function
  - and then binding it to the `q` key
- Let's change the code accordingly

Callbacks

- Our new callback function:

```
def exit_python(event):
    '''Exit Python when the event
       'event' occurs.'''
    quit()  # no arguments to quit
```

- Then, before the **mainloop** line, write:

```
root.bind('<q>', exit_python)
```

- instead of

```
root.bind('<q>', quit)
```

Callbacks

- Now, when we hit the `q` key, the program exits and nothing is printed
- The `exit_python` function received the event and ignored it
  - just calls `quit` without any arguments
  - so nothing is printed
- This is the behavior we wanted
- Now let's try some variations on this

Handling different events

- Change `'<q>'` to `'<Key>'`:

```
root.bind('<Key>', exit_python)
```

- Now, the program will exit when *any* key on the keyboard is pressed, not just the `q` key

- Change `'<Key>'` to `'<Button-1>'`

```
root.bind('<Button-1>', exit_python)
```

- Now the program will exit when the left mouse button (called "Button-1" by `Tkinter`) is clicked

root *vs* canvas

- So far, we've been binding event handlers (callback functions) to the `root` object
- This is not the only `Tkinter` object that can handle events
- The `canvas` object can also handle events by itself
- Can try binding event handlers to the canvas object instead of the root object

root *vs* canvas

- Let's replace the line:

```
root.bind('<q>', exit_python)
```

- with

```
c.bind('<q>', exit_python)
```

- (`c` was the name of the canvas object)
- Run our program again...
- hit the `q` key, and...
- Nothing happens!

root *vs* canvas

- The canvas object doesn't handle key press events!
- Instead, it passes them on to its parent object (the `root` object)
- <u>The point</u>: graphical objects may not be able to handle every kind of event!
- However...

root *vs* canvas

- Let's replace the line:

```
root.bind('<q>', exit_python)
```

- with

```
c.bind('<Button-1>', exit_python)
```

- This *will* work!
- Canvas objects *do* handle mouse button events
- When working with graphical objects, need to know what events they can handle

Continuing...

- Now, we'll look at more interesting callback functions

Outline of our programs

- We're going to work through a few graphics programs
- Each will have the same overall structure
- Details will be different
  - drawing functions
  - callback functions

Outline of our programs

```
from Tkinter import *
import random

<drawing functions>
<callback functions>

if __name__ == '__main__':
    # Set everything up and go.
```

`__name__`

- Inside a module, the variable `__name__` is set to be
  - the name of the module (when the module is imported)
  - the special name `'__main__'` (when the module is run directly by Python)
- Let's see how this works

__name__

- Here's a simple module: `example.py`

```
# module: example.py
print 'My name is: %s' % __name__
```

- It defines a Python module called `example`
- When it's imported, this code will be run
- Let's import it from other Python code:

```
>>> import example
My name is: example
```

- Nothing strange so far...

__name__

- What happens when the file `example.py` is executed directly by Python instead of imported?
  - *e.g.* at the terminal command line

```
% python example.py
My name is: __main__
```

- This says: `example.py` is the first thing executed by Python

if __name__ == '__main__':

- We can use this to define some code in a module which only executes if the module is the first thing Python executes:

```
# example.py
if __name__ == '__main__':
    print 'This is the main module.'
```

`if __name__ == '__main__':`

- Now, at the terminal command line:

```
% python example.py
This is the main module.
```

`if __name__ == '__main__':`

- But when importing the module in the Python shell:

```
>>> import example
```

- Nothing happens!
- Can use this trick to execute some code *only* when a module is loaded as the main module

Outline of our programs

```
from Tkinter import *
import random

<drawing functions>
<callback functions>

if __name__ == '__main__':
    # Set everything up and go.
```

Outline of our programs

```
<... as before ...>

if __name__ == '__main__':
    root = Tk()
    root.geometry('800x600')
    canvas = Canvas(root, width=800, height=600)
    canvas.pack()

    <... Code to set up event handlers. ...>

    root.mainloop()  # Start the event loop.
```

Program 1: Overview

- This program will
  - quit when `q` is pressed
  - print out the (x, y) coordinates of the mouse cursor (relative to the window) when the left mouse button is clicked

Program 1: Last part

```
if __name__ == '__main__':
    <set up root and canvas>

    root.bind('<q>', exit_python)
    canvas.bind('<Button-1>', button_handler)

    root.mainloop()
```

Program 1: Bindings

- `root.bind('<q>', exit_python)`
- (`q` key calls the `exit_python` function)

- `canvas.bind('<Button-1>', button_handler)`
- (Clicking left mouse button calls the `button_handler` function)

Program 1: Callback functions

```
def exit_python(event):
    '''Exit Python.'''
    quit()

def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

Program 1: Callback functions

```
def exit_python(event):
    '''Exit Python.'''
    quit()
```

Have seen this before

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

Program 1: Callback functions

```
def exit_python(event):
    '''Exit Python.'''
    quit()
```

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

This is new

A mouse click event

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

- When you click on the mouse, **`Tkinter`** creates an *event object* that contains all the relevant data about the event
- We have bound this kind of event to the **`button_handler`** callback function

A mouse click event

left-mouse-button-click event object

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

- Tkinter calls **`button_handler`** with the event object as its only argument

A mouse click event

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

- The event object contains two useful pieces of data: **`event.x`** and **`event.y`**
- They represent the x and y coordinates of the mouse cursor when the left mouse button was clicked
  - Coordinates are in pixels, relative to the root window

Aside: Object attributes

- `event.x` and `event.y` are *attributes* of the `event` object
- Mostly we have been using *methods* of objects
- Methods are attributes that happen to be functions
- Objects can also have non-function attributes
- Here, `event.x` and `event.y` are both integers (coordinates in pixels)

A mouse click event

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    print 'x = %d, y = %d' % (event.x, event.y)
```

- When the left mouse button gets clicked, this function will get the event object
- It will print out the x and y coordinates of the mouse cursor

Program 1 Demo

- See it in action...

Moving on

- Now that we can capture the x and y coordinates of the mouse cursor, there are lots of things that we can do with this information
- This leads us to program 2
- Clicking on the mouse will draw a square at the x, y coordinate where the mouse cursor is
  - random color, random size
- Only need to make a couple of changes

Program 2

- Extra graphics command:

```
def draw_random_square(canvas, x, y, \
                       min_size, max_size):
    # ... code omitted ...
```

- This function takes
  - a canvas
  - an (x, y) pair of coordinates
  - a minimum and maximum size
  - and draws a randomly-colored square of a random size between the minimum and maximum values

Program 2

- Extra graphics command:

```
def draw_random_square(canvas, x, y, \
                       min_size, max_size):
    # ... code omitted ...
```

- We'll assume this has been defined

Program 2

- Change **button_handler** callback function

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    draw_random_square(canvas,
                       event.x, event.y,
                       50, 150)
```

- That's it for changes!

Program 2 Demo

- See it in action...

Global variables

- One subtle thing in program 2:

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    draw_random_square(canvas,
                       event.x, event.y,
                       50, 150)
```

- Where does the **canvas** come from?
  - Not an argument to this function

Global variables

- Later in the code we have:

```
root = Tk()
root.geometry('800x600')
canvas = Canvas(root, width=800, height=600)
canvas.pack()
```

- This is the **canvas** that was being referred to
- It is a *global variable*
- That just means that it was defined outside of any function
  - sometimes referred to as the "top level" of the program

Global variables

- Python lets you use global variables
  - Most of the time, want to avoid using them
- A global variable can be changed by *any* function
  - so if it gets the wrong value assigned to it, it can be very hard to find out which function was responsible
- A variable defined inside a function is a *local variable*
- Local variables can only be changed inside the function they were defined in

Global variables

- Local variables are much safer than global variables
- Try to avoid using global variables whenever possible
- So...
  - why are we using one here?
  - Why not just pass the `canvas` object as another argument to the `draw_random_square` callback function?

Back to callback functions

- Answer: callback functions are required to take only *one* argument
  - which must represent the event that activates them
- This is a limitation of `Tkinter`'s design
- `Tkinter` doesn't know how many arguments a particular callback function might want in addition to the event
  - and even if it did, it wouldn't know what to put there
- So any additional data has to be passed via global variables (ugly)

Preview: classes

- There is a "nice" solution to this problem which does not require global variables
- Will involve Python classes
  - user-defined object types
- We will see much more about classes starting later in your life
- For now, we'll stick to using global variables
  - (and hold our noses)

Graphical object handles

- So far we've seen how to create graphical objects
  - directly as part of the program
  - through user interaction with callback functions
- However, once we've created an object, we haven't done anything with it
- It would be useful to be able to manipulate an object after it's created
  - to move it, change it in some way, delete it

Graphical object handles

- `Tkinter` has had this ability all along
  - We just haven't been using it!
- `Tkinter` canvas commands to create graphical objects return a value
- This value is called a handle to the graphical object
  - It is *not* the graphical object itself!

Handles and handlers

- Don't confuse *event handlers* (functions which are called when certain events happen) with canvas graphical object *handles*
  - (no relationship whatsoever between the two concepts)
- A handle is just an integer which represents a particular graphical object on a canvas

Handles and handlers

- Canvases don't let you directly manipulate the objects they contain
  - have to do it indirectly through the object handles
- In other words, graphical objects on canvases
  - like rectangles, ovals, lines, etc.
- are not exposed as Python objects
- The only way to do anything to them is through canvas methods that require handles as arguments

Example: deleting objects

- Our programs have created a bunch of graphical objects (squares) on a canvas
- After a while, a canvas can get very cluttered
- Might want to delete some or all of the existing squares
- Can do this easily using handles

Example: deleting objects

- We will extend our program so that pressing the `c` key (`c` for clear) will remove all the squares from the canvas

Revising our drawing functions

- Before we mentioned this function:

```
def draw_random_square(canvas, x, y, \
                       min_size, max_size):
    # ... code omitted ...
```

- Somewhere in this function there would need to be a call to

```
canvas.create_rectangle(...)
```

- Whatever this method returns, we ignore
- And `draw_random_square` doesn't return anything

Revising our drawing functions

- We will change this line to:

```
square = canvas.create_rectangle(...)
```

- And we will make `draw_random_square` return this value
- `square` is just a Python `int`
  - not some kind of fancy Python object with attributes etc.
- For instance, if it was 5, that would mean "the 5th object created on this canvas"
- Properties of the object stored inside the canvas

Storing object handles

- OK, so `draw_random_square` returns a handle to a square object on a particular canvas
- We want to store this so we can delete the square later on
- We will create a (global) list of squares and add every new square to the list

Storing object handles

- At the end of the program:

```
if __name__ == '__main__':
    root = Tk()
    root.geometry('800x600')
    canvas = Canvas(root, width=800, height=600)
    canvas.pack()
    squares = []

    <rest of code as before>
```

- Now we can store all handles to squares in the (global) list called **squares**

Storing object handles

- Modify the **button_handler** callback function:

```
def button_handler(event):
    '''Handle left mouse button click events.'''
    square = draw_random_square(canvas,
                                event.x, event.y,
                                50, 150)
    squares.append(square)
```

- All newly-created handles to squares are appended to the global **squares** list

Storing object handles

- Change the callback function for key presses:

```
def key_handler(event):
    '''Handle key press events.'''
    key = event.keysym
    if key == 'q':
        quit()
    elif key == 'c':
        for square in squares:
            canvas.delete(square)

# Later in the code:
root.bind('<Key>', key_handler)
```

Key events

```
root.bind('<Key>', key_handler)
```

- This line says: every time a key is pressed on the keyboard, call the **`key_handler`** callback function
  - passing it the **`event`** object corresponding to the key press event

Key events

- The key handler callback function:

```
def key_handler(event):
    '''Handle key press events.'''
    key = event.keysym
    ...
```

- Key press event objects have an attribute called a **`keysym`**
- This is basically just the character on the key that was pressed
  - so **`'q'`** for the `q` key, **`'c'`** for the `c` key, etc.

Key events

```
def key_handler(event):
    '''Handle key press events.'''
    key = event.keysym
    if key == 'q':
        quit()
    elif key == 'c':
        for square in squares:
            canvas.delete(square)
```

- This makes the `q` key quit Python as before

Key events

```
def key_handler(event):
    '''Handle key press events.'''
    key = event.keysym
    if key == 'q':
        quit()
    elif key == 'c':
        for square in squares:
            canvas.delete(square)
```

- This makes the `c` key delete all the squares from the canvas
  - using the `canvas.delete` method

Program 3 Demo

- See it in action...

Modifying global variables

- One problem with this approach:
- The squares in the `squares` list were deleted using the `canvas.delete` method
- But the `squares` list itself wasn't emptied out
- Let's try to do that now

Modifying global variables

```
def key_handler(event):
    ...
    elif key == 'c':
        for square in squares:
            canvas.delete(square)
        squares = []
```

- Here, we're trying to change the global variables **`squares`** by assigning the empty list to it
- Only one problem: it won't work!

Modifying global variables

```
def key_handler(event):
    ...
    elif key == 'c':
        for square in squares:
            canvas.delete(square)
        squares = []
```

- Python has no way of knowing that **`squares`** is supposed to represent a global variable
- It could just as well be a *local* variable that we just decided to create at that point in the function

Modifying global variables

```
def key_handler(event):
    ...
    elif key == 'c':
        for square in squares:
            canvas.delete(square)
        squares = []
```

- When in doubt, Python assumes that a variable is a local variable, not a global variable
- How do we tell it "`squares` is supposed to be a global variable, not a local variable"?

Modifying global variables

```
def key_handler(event):
    global squares
    ...
    elif key == 'c':
        for square in squares:
            canvas.delete(square)
        squares = []
```

- The **global** declaration tells Python that **squares** refers only to a global variable inside the **key_handler** function
- Now, the global **squares** array will be cleared every time the **c** key is pressed

Modifying global variables

- The `global` declaration is only needed if you intend to *change* what the global variable name is bound to (*i.e.* to a new object)
- If you just want to do something with it (like append something to a global list) you don't need the `global` declaration
- So we didn't need it in `button_handler` when we had the line:

```
squares.append(square)
```

- because `squares` is still the same list object

Next lecture

- More graphics
- Widgets!
  - buttons, menus, etc.