Procedures

Arguments to procedures

Extended example

Returning values

Continuing the example

Pseudocode

Scripting

Summary

MAT 305: Mathematical Computing

Procedures

John Perry

University of Southern Mississippi

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Procedures?

- sequence of statements organized as one command
  - may return one or more values
- other languages:

Ada, Pascal	`procedure` and `function`
BASIC	subroutine
C, C++, Kotlin, Python, VB	function
Eiffel	`feature`
Java	method

- We use “procedure” to avoid confusion w/mathematical functions

Why procedures?

- avoid retyping code
  - many patterns repeated
  - same behavior, different data
- organization, abstraction
- easier to read, maintain

Defining a procedure

`def` *name*`(` *argument1*`=`*default1* `,` *argument2*`=`*default2* `, ...):`

statement1

statement2

...

where

- *name* is an identifier
- *arguments* (optional) are identifiers
- *defaults* (optional) are default values for the corresponding arguments

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Defining a procedure

`def` *name*`(` *argument1=default1* `,` *argument2=default2* `, ...):`

statement1

statement2

...

where

- *name* is an identifier
- *arguments* (optional) are identifiers
- *defaults* (optional) are default values for the corresponding arguments

***not** optional:*

- `:`, `()`, `def`
- *at least one statement*
- *indent all statements* in procedure

Calling a procedure

- once `p` is defined, call using `p()`
- supply data for arguments without default values

Example

```
def greetings():
  # greet the user
  print 'Greetings!'
```

- name of procedure is `greetings`
- no arguments
- one statement
- one comment (`# greet the user`)
  - ignored by computer
  - useful for programmers

Example

Try it!

```
sage:  def greetings():
         # greet the user
         print 'Greetings!'
sage:  greetings()
Greetings!
```

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Arguments?

placeholders for data

scope: identifier valid only inside procedure where it is defined

- data still exists outside procedure
- modifying argument does not modify original data, but creates new data
  - *caveat:* contents of lists and sets can be modified
- value of data forgotten immediately after procedure concludes

Example

```
def greetings(name='Leonhard Euler'):
  print 'Greetings,', name
```

- name of procedure is `greetings`
- one argument, `name`
  - default value: `'Leonhard Euler'`

Example

Try it!

```
sage:  def greetings(name='Leonhard Euler'):
         print 'Greetings,', name

sage:  greetings()
Greetings, Leonhard Euler
```

Example

Try it!

```
sage:  def greetings(name='Leonhard Euler'):
           print 'Greetings,', name

sage:  greetings()
Greetings, Leonhard Euler

sage:  greetings('Pythagoras')
Greetings, Pythagoras
```

Example

Try it!

```
sage:  def greetings(name='Leonhard Euler'):
           print 'Greetings,', name

sage:  greetings()
Greetings, Leonhard Euler

sage:  greetings('Pythagoras')
Greetings, Pythagoras

sage:  greetings(name='Pythagoras')
Greetings, Pythagoras
```

Example

Try it!

```
sage:  def greetings(name='Leonhard Euler'):
         print 'Greetings,', name

sage:  greetings()
Greetings, Leonhard Euler

sage:  greetings('Pythagoras')
Greetings, Pythagoras

sage:  greetings(name='Pythagoras')
Greetings, Pythagoras

sage:  greetings(pi)
Greetings, pi
```

Warning 1

Don't use uninitialized identifiers

```
sage:  def greetings(name='Leonhard Euler'):
         print 'Greetings,', name

sage:  greetings(Pythagoras)                    oops: no quotes!
...Output deleted...
NameError:  name 'Pythagoras' is not defined
```

Warning 2

Scope implies `name` does not exist outside `hello`

```
sage:  def greetings(name='Leonhard Euler'):
         print 'Greetings,', name

sage:  greetings('Pythagoras')
Hello, Pythagoras

sage:  name
...Output deleted...
NameError:  name 'name' is not defined
```

`name` *out of scope*

Warning 3

Scope implies `name` forgotten once `hello` concludes

```
sage:  def greetings(name='Leonhard Euler'):
           print 'Greetings,', name

sage:  greetings('Pythagoras')
Hello, Pythagoras

sage:  greetings()
Hello, Leonhard Euler
```

name has value `'Leonhard Euler'` *again*

Warning 4

Can change value inside procedure, but value outside procedure remains the same

```
sage:  def mischievous_hello(name='world'):
           name = 'loser!'
           print 'Hello,', name
```

Warning 4

Can change value inside procedure, but value outside procedure remains the same

```
sage:  def mischievous_hello(name='world'):
           name = 'loser!'
           print 'Hello,', name

sage:  print_name = 'Dr.  Perry'
sage:  mischievous_hello(print_name)
Hello, loser!
```

value of `name` *changed in procedure*

Warning 4

Can change value inside procedure, but value outside procedure remains the same

```
sage:  def mischievous_hello(name='world'):
         name = 'loser!'
         print 'Hello,', name

sage:  print_name = 'Dr.  Perry'
sage:  mischievous_hello(print_name)
Hello, loser!                    value of name changed in procedure

sage:  print_name
'Dr.  Perry'                     value of print_name unchanged
```

Warning 5

If defaults are not given to arguments, you must supply something

```
sage:  def greetings(name):
           print 'Greetings,', name

sage:  greetings()
```

...*Output deleted*...

```
TypeError:  greetings() takes exactly 1 argument (0 given)
```

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A mathematical problem

Given function f and real number a

find line tangent to f at $x = a$

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A mathematical problem

Given function f and real number a

find line tangent to f at $x = a$

How should we implement this?

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A mathematical problem

Given function f and real number a

find line tangent to f at $x = a$

How should we implement this?

```
sage:  def tangent_line(f, a):
           # point-slope form of a line
```

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A mathematical problem

Given function f and real number a

find line tangent to f at $x = a$

How should we implement this?

```
sage:  def tangent_line(f, a):
           # point-slope form of a line
           b = f(a)
           df(x) = diff(f,x)
           m = df(a)
           result = m*(x - a) + b
```

A mathematical problem

Given function f and real number a

find line tangent to f at $x = a$

How should we implement this?

```
sage:  def tangent_line(f, a):
           # point-slope form of a line
           b = f(a)
           df(x) = diff(f,x)
           m = df(a)
           result = m*(x - a) + b
           print 'The line tangent to', f,
           print 'at x =', a, 'is',
           print result
```

Quick test

```
sage:  f(x) = x^2
sage:  tangent_line(x^2, 1)
The line tangent to x |--> x^2
at x = 1 is
2*x - 1
```

Trouble is...

...it sometimes complains!

```
sage:  tangent_line(x^2, 1)
```

...*Output deleted*...

```
DeprecationWarning:  Substitution using
function-call syntax and unnamed arguments is
deprecated and will be removed from a future release
of Sage; you can use named arguments instead, like
EXPR(x=..., y=...)
```

...*Output deleted*...

```
The line tangent to x^2 at x = 1 is 2*x - 1
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...it sometimes complains!

```
sage:  tangent_line(x^2, 1)
```

...*Output deleted*...

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```

...*Output deleted*...

```
The line tangent to x^2 at x = 1 is 2*x - 1
```

Problematic line: `b = f(a)`

- `f` has value `x^2` , an *expression*
  - `b = f(a)` wants f to be a *function*

Solution #1

Define `f` as function, call `tangent_line()` w/`f`

```
sage:  f(x) = x^2
sage:  tangent_line(f, 1)
The line tangent to x |--> x^2 at x = 1 is 2*x - 1
```

Solution #1

Define `f` as function, call `tangent_line()` w/`f`

```
sage:  f(x) = x^2
sage:  tangent_line(f, 1)
The line tangent to x |--> x^2 at x = 1 is 2*x - 1
```

Inconvenient, though: `tangent_line(x^2, 1)` would be useful.

Solution #2

Specify variable of substitution in procedure:

```
sage:  def tangent_line(f, a):
         # point-slope form of a line
         b = f(x=a)
         df(x) = diff(f,x)
         ...
```

Solution #2

Specify variable of substitution in procedure:

```
sage:  def tangent_line(f, a):
         # point-slope form of a line
         b = f(x=a)
         df(x) = diff(f,x)
         ...
sage:  tangent_line(x^2, 1)
The line tangent to x |--> x^2 at x = 1 is 2*x - 1
```

Also undesirable. *Why?*

Solution #2

Specify variable of substitution in procedure:

```
sage:  def tangent_line(f, a):
         # point-slope form of a line
         b = f(x=a)
         df(x) = diff(f,x)
         ...
sage:  tangent_line(x^2, 1)
The line tangent to x |--> x^2 at x = 1 is 2*x - 1
```

Also undesirable. *Why?*

```
sage:  var('t')
sage:  tangent_line(t^2, 1)
The line tangent to x |--> t^2 at x = 1 is t^2
```

Solution #3

Redefine expression as function:

```
sage:  def tangent_line(f, a):
           # redefine f
           f(x) = f
           # point-slope form of a line
           b = f(a)
           ...
```

Solution #3

Redefine expression as function:

```
sage:  def tangent_line(f, a):
           # redefine f
           f(x) = f
           # point-slope form of a line
           b = f(a)
           ...
sage:  tangent_line(x^2, 1)
The line tangent to t |--> t^2 at x = 1 is 2*x - 1
```

Better, but insufficient. *Why?*

Solution #3

Redefine expression as function:

```
sage:  def tangent_line(f, a):
           # redefine f
           f(x) = f
           # point-slope form of a line
           b = f(a)
           ...
sage:  tangent_line(x^2, 1)
The line tangent to t |--> t^2 at x = 1 is 2*x - 1
```

Better, but insufficient. ***Why?***
Why should t change to x?

Best (?) solution

Redefine as function in indeterminate:

```
sage:  def tangent_line(f, a, x=x):
           # redefine f
           f(x) = f
           # point-slope form of a line
           b = f(a)
           df(x) = diff(f,x)
           m = df(a)
           result = m*(x - a) + b
           print 'The line tangent to', f,
           print 'at', x, '=', a, 'is',
           print result
```

Best (?) solution

Redefine as function in indeterminate:

```
sage:  def tangent_line(f, a, x=x):
           # redefine f
           f(x) = f
           # point-slope form of a line
           b = f(a)
           df(x) = diff(f,x)
           m = df(a)
           result = m*(x - a) + b
           print 'The line tangent to', f,
           print 'at', x, '=', a, 'is',
           print result
sage:  tangent_line(t^2, 1)
The line tangent to t |--> t^2 at t = 1 is 2*t - 1
```

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Returning values?

- procedures compute values
- Often want to work with what we've computed
  - `print` command unhelpful
  - copy and paste annoying

Example

Derivative necessary to compute many things:

- graph tangent line
- analyze concavity
- identify optimum values
- …

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The `return` command

`return` *value1*, *value2*, ...

- reports the data values *value1*, *value2*, etc. to caller
- only works inside procedures

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Problem

Write a procedure whose arguments are

- a function f,
- numbers $[a, b]$,
- a number $c \in (a, b)$,
- an indeterminate x,

and returns both f and the line tangent to it at $x = c$ on $[a, b]$.

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Divide and conquer

How can we break this into smaller tasks?

Divide and conquer

How can we break this into smaller tasks?

1. Compute line tangent to f at c
2. Plot f on $[a, b]$
3. Plot line on $[a, b]$
4. Return their sum

Divide and conquer

How can we break this into smaller tasks?

1. Compute line tangent to f at c — already solved
2. Plot f on $[a, b]$
3. Plot line on $[a, b]$
4. Return their sum

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Summary

Tangent line: modify implementation

```
sage:  def tangent_line(f, a, x=x):
           # redefine f
           f(x) = x
           # point-slope form of a line
           b = f(x=a)
           df(x) = diff(f,x)
           m = df(a)
           result = m*(x - a) + b
           return result
```

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Tangent line: modify implementation

```
sage:  def tangent_line(f, a, x=x):
         # redefine f
         f(x) = x
         # point-slope form of a line
         b = f(x=a)
         df(x) = diff(f,x)
         m = df(a)
         result = m*(x - a) + b
         return result
sage:  tangent_line(t^2, 1, t)
2*t - 1
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
           # compute the line
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
           # compute the line
           tan_line = tangent_line(f, c, x)
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
         # compute the line
         tan_line = tangent_line(f, c, x)
         # plot of f
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
           # compute the line
           tan_line = tangent_line(f, c, x)
           # plot of f
           f_plot = plot(f, a, b)
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
           # compute the line
           tan_line = tangent_line(f, c, x)
           # plot of f
           f_plot = plot(f, a, b)
           # plot of line
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
         # compute the line
         tan_line = tangent_line(f, c, x)
         # plot of f
         f_plot = plot(f, a, b)
         # plot of line
         tan_plot = plot(tan_line, a, b)
```

Use to plot

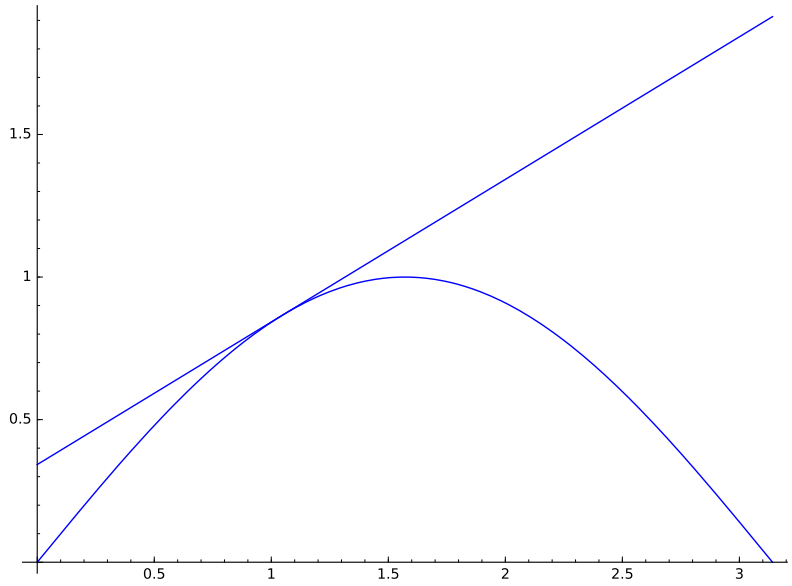
```
sage:  def tangent_plot(f, a, b, c, x=x):
         # compute the line
         tan_line = tangent_line(f, c, x)
         # plot of f
         f_plot = plot(f, a, b)
         # plot of line
         tan_plot = plot(tan_line, a, b)
         # combine & return
```

Use to plot

```
sage:  def tangent_plot(f, a, b, c, x=x):
         # compute the line
         tan_line = tangent_line(f, c, x)
         # plot of f
         f_plot = plot(f, a, b)
         # plot of line
         tan_plot = plot(tan_line, a, b)
         # combine & return
         return f_plot + tan_plot
```

Result

```
sage: tangent_plot(sin(x), 0, pi, pi/3)
```



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Pseudocode?

description of algorithm

- many formats
- format independent of computer language
- prefer mathematics to programming
  - "ith element of L" or "L_i", not `L[i-1]`

Our pseudocode format

algorithm *name*

inputs

input1 $\in$ *domain1*

input2, *description of type*

…

outputs

output1, *relationship to inputs*

output2, *relationship to inputs*

…

do

English or mathematical statement 1

English or mathematical statement 2

…

Our pseudocode format

algorithm *name*

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input1 $\in$ *domain1*

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output1, *relationship to inputs*

output2, *relationship to inputs*

…

do

English or mathematical statement 1

English or mathematical statement 2

…

Try it now on the given problem

Example problem

Write a program to compute the line tangent to $f(x)$ at $x = x_0$.

- Write pseudocode answering:
  1. What inputs will we need?
     - domain of each input (what set/type of object)
  2. What outputs do we expect?
     - inputs' purpose & relationship to output
  3. How do we use the inputs to generate the output?
     - think step-by-step
     - do a sample problem: $f(x) = x^2$, $x_0 = 3$
     - think about possible errors errors
- Implement pseudocode

Example pseudocode

algorithm *tangent_line*

inputs

f, a function of a variable x

$x_0 \in \mathbb{R}$

Example pseudocode

algorithm *tangent_line*

inputs

f, a function of a variable x

$x_0 \in \mathbb{R}$

outputs

the line tangent to $f(x)$ at $x = x_0$

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Example pseudocode

algorithm *tangent_line*

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f, a function of a variable x

$x_0 \in \mathbb{R}$

outputs

the line tangent to $f(x)$ at $x = x_0$

do

— *We need two things for a line: a point* (x_0, y_0) *and the slope* m

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the line tangent to $f(x)$ at $x = x_0$

do

— *We need two things for a line: a point* (x_0, y_0) *and the slope* m

Let $y_0 = f(x_0)$

— *Use Calculus to find* m

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the line tangent to $f(x)$ at $x = x_0$

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— *We need two things for a line: a point* (x_0, y_0) *and the slope* m

Let $y_0 = f(x_0)$

— *Use Calculus to find* m

Let $fderiv = f'(x)$

Let $m = fderiv(x_0)$

Example pseudocode

algorithm *tangent_line*

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f, a function of a variable x

$x_0 \in \mathbb{R}$

outputs

the line tangent to $f(x)$ at $x = x_0$

do

— *We need two things for a line: a point* (x_0, y_0) *and the slope* m

Let $y_0 = f(x_0)$

— *Use Calculus to find* m

Let $fderiv = f'(x)$

Let $m = fderiv(x_0)$

— *Point-slope form:* $y - y_0 = m(x - x_0)$

Let $line = m(x - x_0) + y_0$

Example pseudocode

algorithm *tangent_line*

inputs

f, a function of a variable x

$x_0 \in \mathbb{R}$

outputs

the line tangent to $f(x)$ at $x = x_0$

do

— *We need two things for a line: a point* (x_0, y_0) *and the slope* m

Let $y_0 = f(x_0)$

— *Use Calculus to find* m

Let $fderiv = f'(x)$

Let $m = fderiv(x_0)$

— *Point-slope form:* $y - y_0 = m(x - x_0)$

Let $line = m(x - x_0) + y_0$

return *line*

Example implementation

Compare to implementation:

```
def tangent_line(f, a, x=x):
        # redefine f
        f(x) = x
        # point-slope form of a line
        b = f(x=a)
        df(x) = diff(f,x)
        m = df(a)
        result = m*(x - a) + b
        return result
```

Example implementation

Compare to implementation:

```
def tangent_line(f, a, x=x):
        # redefine f
        f(x) = x
        # point-slope form of a line
        b = f(x=a)
        df(x) = diff(f,x)
        m = df(a)
        result = m*(x - a) + b
        return result
```

Specify x as input to pseudocode?

- not inherent to *problem*, but to *programming*, so
- do not include in pseudocode, but
- this is arguable

Example run

Behold: *the power of symbolic computation!*

```
sage:  var('a b c')
sage:  tangent_line(a*x^2 + b*x + c, 1, x)
(2*a + b)*(x - 1) + a + b + c
```

Combine with plots

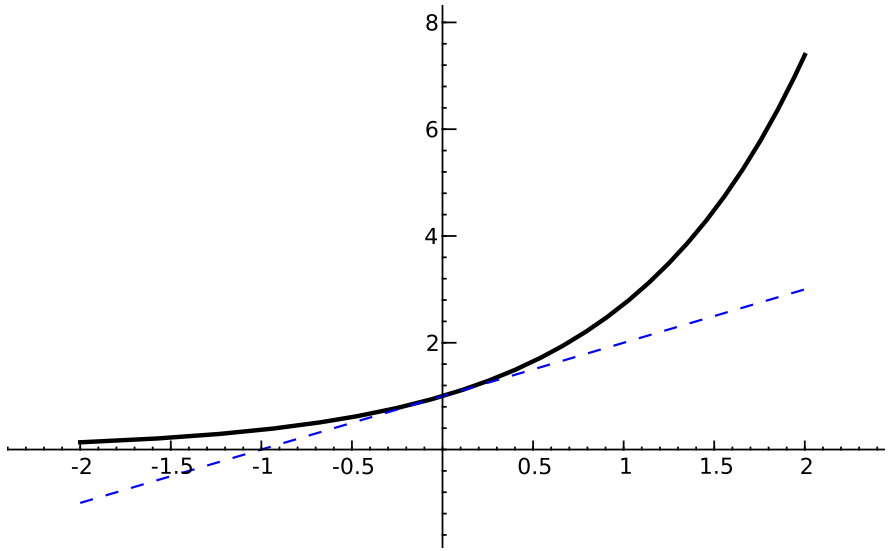
We show the plots of e^x and its tangent line at $x = 0$

```
sage:  f = e^t
sage:  tanline = tangent_line(f, 0, t)
sage:  fplot = plot(f, -2, 2, color='black',
                    thickness=2)
sage:  lineplot = plot(tanline, -2, 2,
linestyle='dashed')
sage:  fplot + lineplot
```

Combine with plots

We show the plots of e^x and its tangent line at $x = 0$

```
sage:  f = e^t
sage:  tanline = tangent_line(f, 0, t)
sage:  fplot = plot(f, -2, 2, color='black',
                    thickness=2)
sage:  lineplot = plot(tanline, -2, 2,
linestyle='dashed')
sage:  fplot + lineplot
```



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Combining procedures

It would be nice to have a procedure that graphs an arbitrary $f(x)$ and its tangent line at $x = x_0$. Options include:

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- Encapsulate commands in another procedure

Pseudocode

algorithm *plot_function_and_tangent*

inputs

f, a function of a variable x

$x_0 \in \mathbb{R}$

outputs

the plot of $f(x)$ and the line tangent to f at $x = x_0$

do

Let P_1 be the plot of $f(x)$ in a neighborhood of x_0

Let $g(x)$ be the line tangent to f at x_0 *Already solved!*

Let P_2 be the plot of $g(x)$ in the same neighborhood of x_0

return P_1 and P_2 combined

Implementation

```
def plot_function_and_tangent(f, x0, x=x,
      xmin=-2, xmax=2):
```

Whitespace

```
  # plots f(x) and line tangent to f at x0
  # over [ xmin, xmax ];
  # returns combination of these plots
```

distinguishes

```
  P1 = plot(f, xmin, xmax, rgbcolor='black',
        thickness=2)
```

different

```
  # next line reuses previous code
  g = tangent_line(f, x0, x)
```

tasks

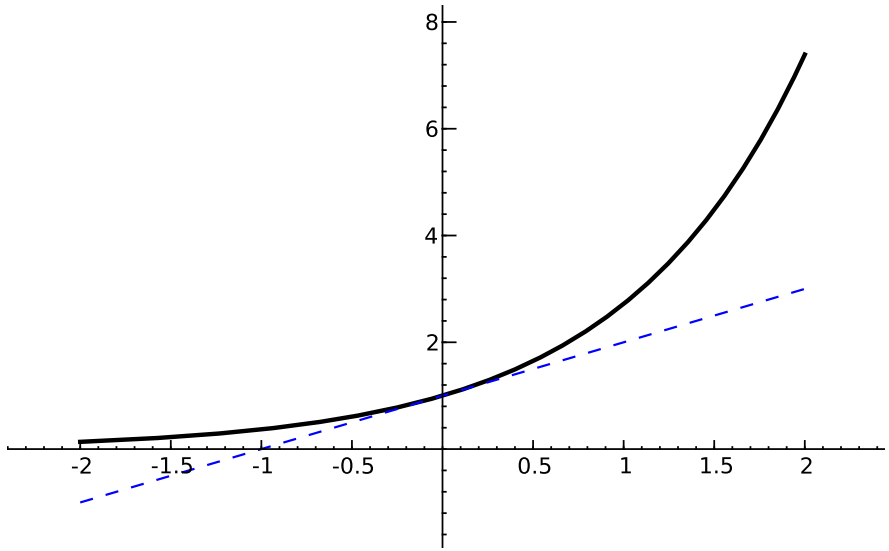
```
  P2 = plot(g, xmin, xmax, linestyle='dashed')
  return P1 + P2
```

Examples

```
sage:  def plot_function_and_tangent...
```

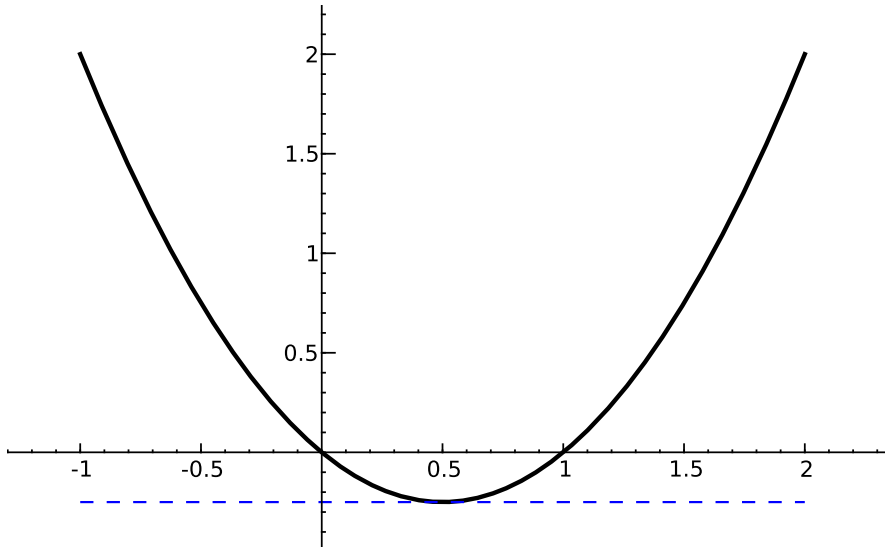
Examples

```
sage:  def plot_function_and_tangent...
sage:  plot_function_and_tangent(e^x,x)
```



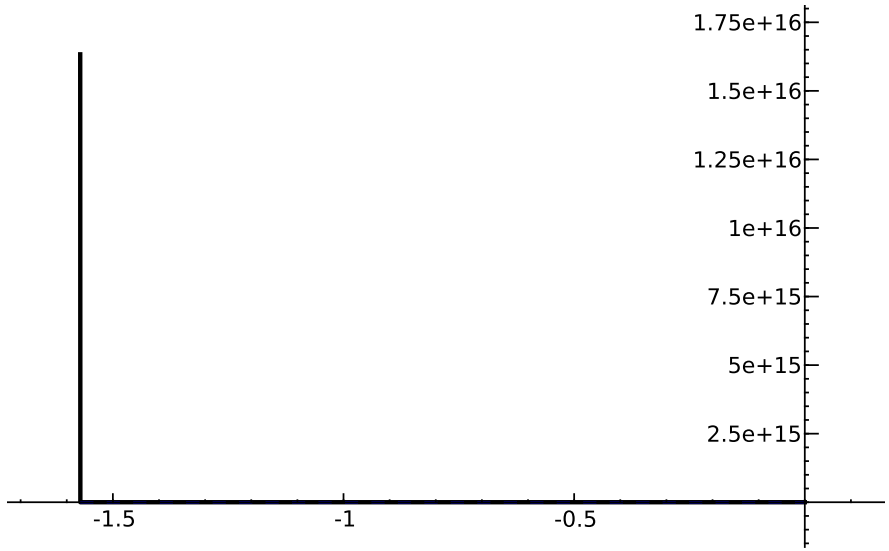
Examples

```
sage:  def plot_function_and_tangent...
sage:  plot_function_and_tangent(x^2-x,0.5,xmin=-1,
         xmax=2)
```



Examples

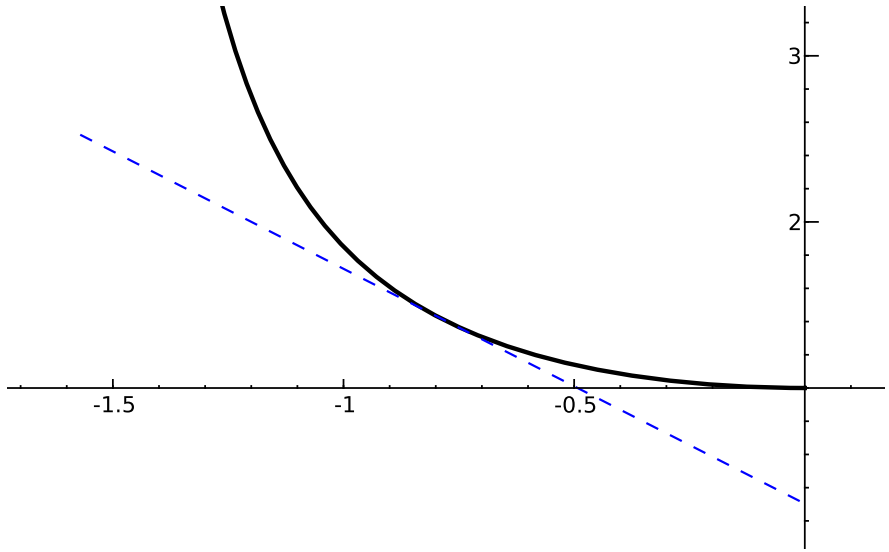
```
sage:  def plot_function_and_tangent...
sage:  plot_function_and_tangent(sec(x),-pi/2,
         xmin=-pi/2,xmax=0)
```



ouch. need to adjust `ymax`

Examples

```
sage:  def plot_function_and_tangent...
sage:  good_sec = plot_function_and_tangent(
         sec(x),
         xmin=-pi/2,x0=-pi/4,xmax=0)
sage:  show(good_sec,ymax=3)
```



Note: `sec(x)` *does not work in older versions, apparently because its derivative is not computed*

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script a sequence of Sage statements saved to a file

- write, save
- load at later date
- no need to type, re-type statements

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script a sequence of Sage statements saved to a file

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Let's script our `tangent_line()` procedure.

Creating a script

- Back to 'Files'
- Type `calc_utils.sage` in "Filename" box
- Choose "Sage Code (.sage)" in "Create" drop-down
- put `tangent_line()` code in new file
- Save, close
  - `calc_utils.sage` appears in list of files!

Using a script

- Create new Sage worksheet
  - or open old one
- "Attach" the script:

```
sage:  attach calc_utils.sage
```

- Try it:

```
sage:  tangent_line(x^2, 1)
2*x - 1
```

Using a script

- Create new Sage worksheet
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- "Attach" the script:

```
sage:  attach calc_utils.sage
```

- Try it:

```
sage:  tangent_line(x^2, 1)
2*x - 1
```

- You have now "extended" Sage!
- Can use `tangent_line()` in any worksheet, or even in other scripts, using `%attach` directive

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Summary

- procedures collect several Sage statements into one
  - organizes solutions to problems
  - abstraction makes problem-solving easier
- define using `def(...):`
- procedures receive *arguments* as data
  - can specify default values
  - procedure does not change arguments, *but*...
  - elements of collections can be changed
- Return value(s) using `return`
- Scripts save procedures for later usage