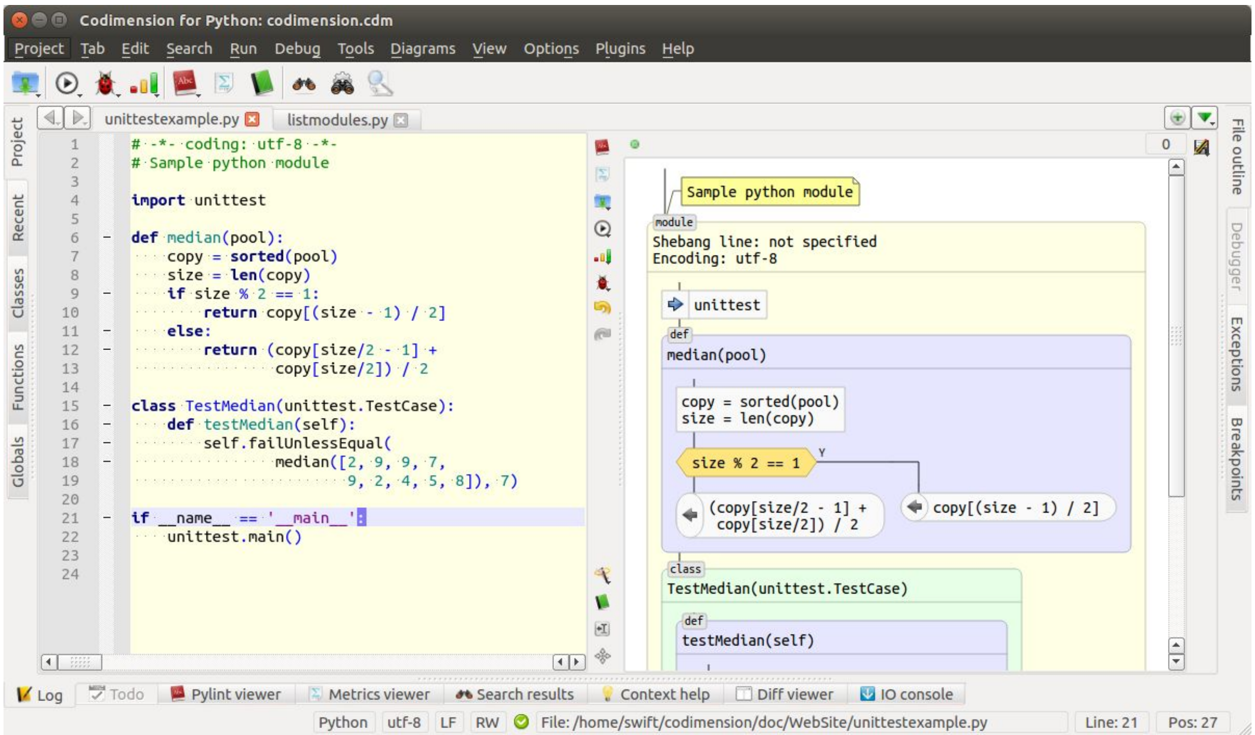
Python Code Visualization

Introduction

The article is about a technology which makes it possible to implement developer tools similar to the shown below.



Common view of an IDE with two ways of representing the code

The IDE window above is split into two parts. A usual text editor resides on the left hand side and on the right hand side there is an automatically generated flowchart-like diagram. The generation and redrawing happen while the user is changing the source code. The IDE detects a pause in typing and updates the diagram if the code stays valid. The result of this approach is that the user can work not only with the text but with its graphics representation as well.

However, before digging into the details of the suggested technology let's discuss some general questions of the software development.

Flow Charts in the Wild

The most essential related question is: do we need flow charts at all?

My experience of software development clearly shows that flowcharts are used and the way they are used depends on a certain task. Two typical scenarios could be recognized:

- developing new software from scratch
- supporting existing software which in most cases is developed by somebody else

In both scenarios I use diagrams, though in different fashions.

In the case of a new development it is usually a top-to-bottom approach. I draw the architecture of the future software as a set of abstract blocks or actors and then I move to more detailed levels eventually reaching the level of the chosen programming language. Certainly, I do not draw everything. I draw only the parts which are of interest to me or the most difficult ones. Unfortunately, tools available on the market, like MS Visio for example, help me only when I work on a high abstraction level. I wish there was a tool which would help me with the lower level too, and preferably in two complementary ways: generating a diagram from code and vice verse.

In the case of maintaining existing code it is the usual – and sad – situation that there is no documentation and I have to reverse engineer the ideas behind the code. So I proceed in a bottom-to-top way. I read the code and when I understand what a chunk of it does I draw – physically on a piece of paper or mentally – a block with an appropriate label on it. Thus I get a single block (or a chunk) with a label instead of a group of statements. Eventually I get a flowchart which corresponds to the code. I wish there was a tool which supports this process conveniently but I have not found it yet.

It also makes sense to consider large scale industrial projects which relied on flowcharts or similar diagrams heavily, if not entirely during the development stage. Are there such projects? The answer to this question is yes and it comes from rocket science. Probably the largest project I am aware of that used flowcharts is the software for the Russian space shuttle called Buran. Unlike the US space shuttles, the Russian one was unmanned and the software did all the work on the way to space and back. During the whole software development process the developers used the programming language called DRAKON and the language uses flowchart-like diagrams on all stages. The developers could not use text at all.

The project proved to be very successful: Buran reached space and came back safe and sound. The reports claim that the low level of software mistakes in the project and the speed of development are due to the chosen approach of using diagrams instead of text. A similar approach is still in use for some space related projects as far as I know.

Unfortunately, modern developers who are using popular programming languages at work cannot use DRAKON due to some constraints of the technology. However, a general conclusion could be made: diagrams, similar to flowcharts are useful and could bring a significant benefit.

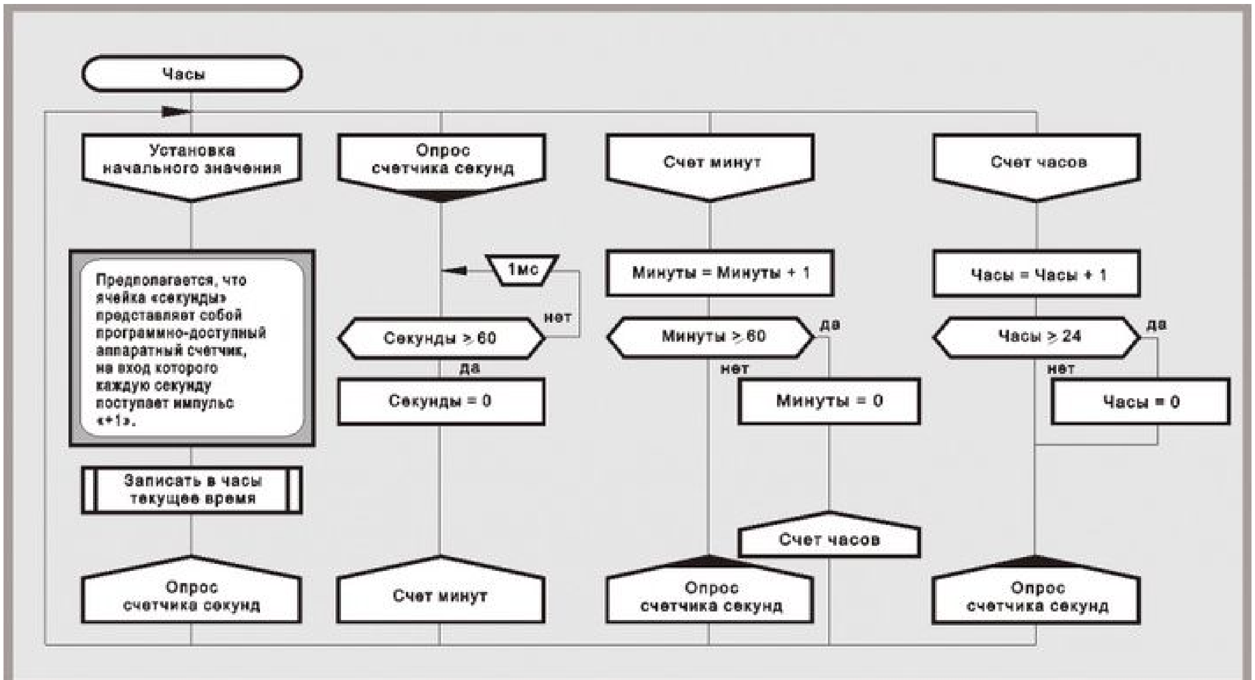


Рис. 89. Алгоритм «Часы».

Example of a DRAKON diagram (from drakon.su)

Available Tools

My understanding of the software engineering is that sometimes it makes more sense to work with the code in a text editor while sometimes it is graphics which delivers the best performance. So ideally I would like to have a tool which supports both: text and graphics, without sacrificing any of the two ways to look at the code. That ideal tool would also provide a smooth and integrated way to switch between the views of the same code.

Sadly there is no such a tool on the market yet. There are generic engineering graphics tools like Dia or MS Visio which are very good at what they are designed for. They can help at some stages but it is hard to use them when there are frequent changes. There are tools which support a design stage - e.g. UML oriented tools - but it is hardly ever possible to use them on a lower level. There are code generators but the generated code in many case is not really for reading it. There are graphics tools - like DRAKON oriented ones - used in their specific application domains but they cannot be used in the general purpose modern projects. They usually sacrifice the text and concentrate on drawing or even do not provide access to the text at all.

So if a suitable tool does not exist then probably it’s worth to develop a technology which opens a possibility of creating it. The further discussion will be about the technology and an experimental IDE implementing it. The IDE lets to look at the existing projects as at text and as at graphics with an automatic synchronization between the views. The implementation is done for Python and mostly in Python.

Graphics Primitives

A good start point for the discussion could be a set of graphics primitives that will be used to represent an arbitrary python code. Let's talk first of moving from text to graphics. At the beginning we have a file with some Python code and at the end we need graphics primitives, appropriately drawn and connected. The following questions need to be answered at this stage. What language elements should be recognized? How exactly the recognized elements should be drawn on a flowchart-like diagram?

The next chapters will discuss all the required graphics primitives one by one.

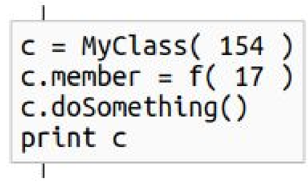
Code Blocks

Certainly not all the language statements affect the control flow directly. The statements which do not affect it could be drawn as code blocks.

Why blocks but not just individual statements? Well, developers tend to group statements into chunks which help to understand the code for the future readers. The chunks are separated from each other with blank lines. This commonly used technique should be respected and reflected on a flowchart diagram.

As for the graphics primitive shape, a plain rectangle seems to be very reasonable for a code block. The examples below show a single code block and a couple of blocks one after another. The only difference in the code of the examples is a blank line between the statements (here and further: each example has a piece of Python code followed by its suggested graphics representation).

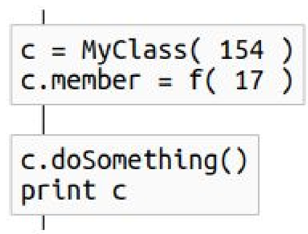
```
c = MyClass( 154 )
c.member = f( 17 )
c.doSomething()
print c
```



One code block

```
c = MyClass( 154 )
c.member = f( 17 )

c.doSomething()
print c
```



Two code blocks one after another

Comments

If a closer look is taken, it is easy to notice that a few types of comments could be identified basing on how a developer located the comments in the code. Similarly to the code blocks, empty lines should be respected because they define chunks of information. The three comments types are:

- Independent
- Leading
- Side comments

The independent comments are those which occupy one or many lines and separated from anything else by at least one empty line. The independent comment lines do not contain anything but comments.

The leading comments are quite similar to the independent ones with one exception. The very next line after a leading comment is a Python statement. A developer did not insert an empty line between the comment and the following block and most probably this is meaningful - the comment is for the following block.

The side comments are those which are located to the right of the statements. There are a few important details about side comments. A code block may occupy a few lines and a developer may want to provide a comment only for a certain line in the block. This fact should be respected. Another detail is that sometimes a developer may want to provide more than one line of comments for the last statement in a code block. Cases like that should also be respected in graphics.

Theoretically it is possible to introduce a trailing type of comments - similarly to the leading type with the difference that there is no empty line between a statement above and the comment. This however seems to have a very minor practical sense. Developers rarely comment on something which is located above. They rather use a leading comment or a side one. Therefore it was decided not to introduce a trailing type of comments.

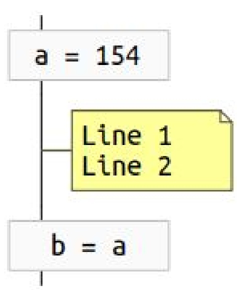
So, how could these three distinguished types of comments be drawn on a diagram?

Independent Comments

```
a = 154

# Line 1
# Line 2

b = a
```

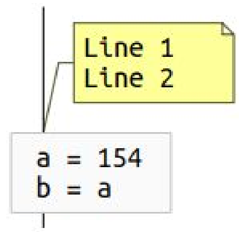


Independent comment

An independent comment in the example above is comprised of two lines. Indeed the comment is between two code blocks and that position corresponds to a connector between the blocks on the diagram. So a reasonable graphics for independent comments would be a note rectangle with a horizontal connector to the appropriate inter block connector.

Leading Comments

```
# Line 1
# Line 2
a = 154
b = a
```

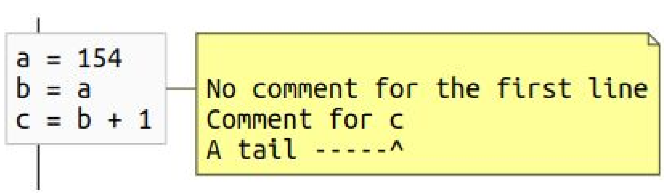


Leading comment

This leading comment is for a code block and has two lines. So what could be done here is to draw the comment note rectangle above the code block and to direct a comment connector to the block.

Side Comments

```
a = 154
b = a         # No comment for the first line
c = b + 1     # Comment for c
              # A tail -----^
```



Side comment with a “tail”

The side comments require to pay attention to a couple of things. The first is that there is usually a line correspondence between the comment and the statement. In this example the author of the code provided a comment only for some statements in the code block. Therefore the graphics representation must keep the line-to-line correspondence between a drawn code block and its side comment.

The second thing to consider is a tail of a side comment. Sometimes a side comment for the last code block statement takes more than a single line as is in the example. The last comment line looks like an independent comment because it does not have a statement before the # character however the author wanted the comment to be for the last statement in the block. A criteria to consider the side comment to be continued on a separate line could be as follows:

- the comment continue line is the very next one and
- the # character is at the same position in the line as in the line above

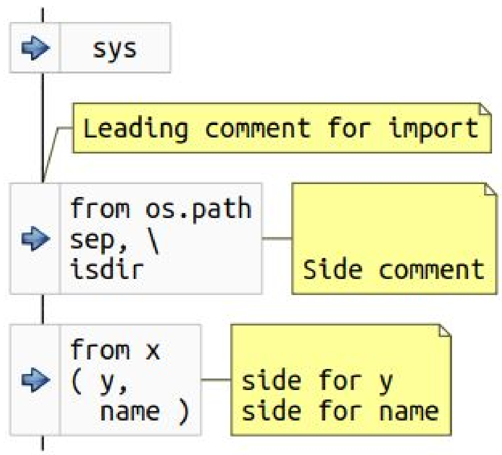
Imports

Essentially imports denote dependencies. The dependencies in their turn can become very difficult to control in large projects. So it would be valuable if a graphics primitive for imports draws attention to the important detail of a Python module even at a quick glance at the diagram. Bearing in mind this reasoning the chosen graphics primitive has an icon on the left as shown below.

```
import sys

# Leading comment for import
from os.path import sep, \
                    isdir     # Side comment

from x import ( y,      # side for y
                name )  # side for name
```



Imports

The second and the third imports in the example occupy more than one line and some of the lines also have side comments.

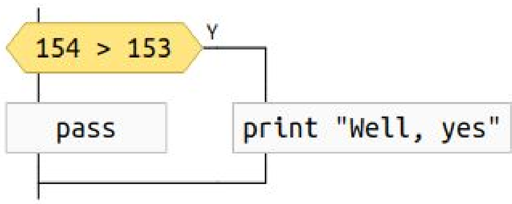
If Statement

Let's discuss how the if statement should look on a graphics diagram. A traditionally recommended shape is a diamond. The diamond shape probably works just fine if a condition is very short. In practice, however, a lot of code has complicated and quite often multilined conditions which are hard to squeeze into a reasonably sized diamond. The diamond will either occupy too much precious vertical space on the screen or the font size will be too small if readable at all or the original condition text needs to be shortened. So the suggestion is to use compromise graphics which have the left and right edges resembling a diamond with the top and bottom edges flat to better use the screen pixel estate. That shape can be easily and naturally scaled to accommodate a condition of an arbitrary complexity.

The second thing to discuss is how to draw the yes and no branches. One of the alternatives here would be to draw them as shoulders on the left and right of a decision block. However, this may lead to a diagram which is hard to read and which does not look nice. The problem comes from the fact that the branches may have arbitrary complexity and in graphics it may lead to very wide shoulders thus shifting the decision block to the right. Consequently it may make browsing the diagram inconvenient because both, the vertical and horizontal scrolling would be required.

One more consideration is about designing the code the way it would be easier to read and understand it later on. It would be nice if there is a way to reside all the actions related to the main purpose of the program on one vertical axis while an unavoidable error and special cases handling would be on a side. Then if the original author took care of it, the others would understand the code quicker. Therefore, to support such a style of coding it was decided to draw the branches as follows: one of them to draw directly under the decision block and the other - to the right of it.

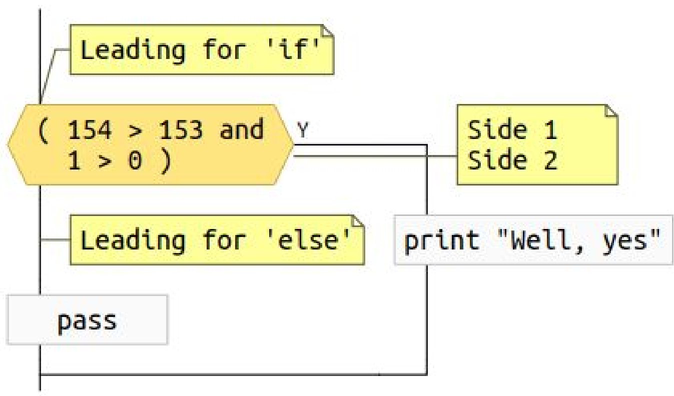
```
if 154 > 153:
    print "Well, yes"
else:
    pass
```



If statement example

Obviously, the author may provide comments for various pieces of code related to the if statement. Let’s consider a more complicated example.

```
# Leading for ‘if’
if ( 154 > 153 and      # Side 1
     1 > 0 ):           # Side 2
    print "Well, yes"
# Leading for ‘else’
else:
    pass
```



If statement with comments

The example in particular has side comments for the condition. Similarly to what was noted for the code block side comments, the condition side comments could be provided only for certain lines. So the condition side comment has to be to the right of the condition and has to be aligned vertically with it. Sadly, no good option was found to avoid crossing connectors on the graphics. There is however a mitigating circumstance - in practice the condition side comments are used rare. In the vast majority of cases developers prefer to use leading comments.

The last interesting detail is about a leading comment for the else part. The graphics does not have any designated primitive for else. In fact else is represented as a connector. So the leading comment for else looks exactly as an independent comment. However there is nothing damaging here. The graphics still represents the code correctly.

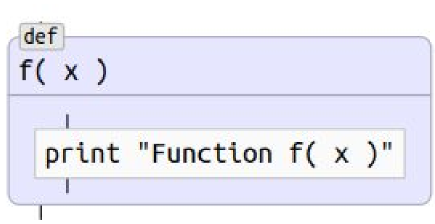
Functions

A Python file may contain many function definitions and even nested function definitions. A commonly accepted graphics for the flowchart diagrams however does not offer anything well suitable for the real life Python functions. So something new needs to be suggested.

When functions are discussed it quite often goes along with the idea of scopes. A scope plays a role of borders space with well defined borders. Certainly a function has very definitive points where it starts and where it ends. So the graphics for a function may use a sort of a closed area within which a function body is drawn. Let’s take a moment and recall a familiar situation. Someone looks at a piece of somebody else’s Python code and has troubles understanding the context. A statement may belong to a function, to a class member, to a condition branch or to a loop body etc. The idea of a rectangle area with explicitly drawn borders may help to understand the current context quicker.

Let’s consider an example of a simple function definition and the suggested graphics for it.

```
def f( x ):
    print "Function f( x )"
```

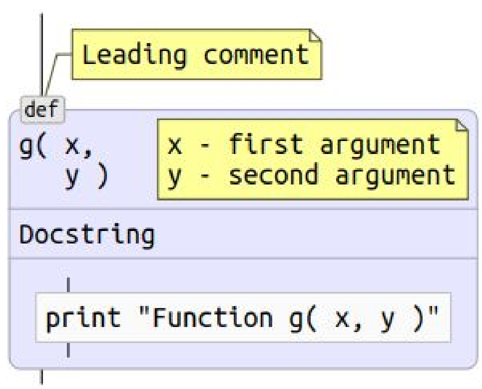


A simple function definition

The function is within a rounded rectangle which is filled with a color specific for functions. The rectangle has a header where the function name and the arguments reside. The function body resides below and is separated from the header with a horizontal line. To make it more obvious that the scope is for a function the rectangle is augmented with a badge in the upper left corner.

Sometimes the real world Python functions might be a bit more complicated. They may have a leading comment, a docstring, the arguments may also have comments and may occupy many lines. Here is another example below for a function featuring the mentioned items.

```
# Leading comment
def g( x,     # x - first argument
       y ):   # y - second argument
    """ Docstring """
    print "Function g( x, y )"
```



Function with a docstring and comments

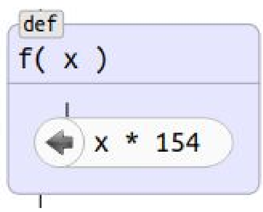
The leading comment graphics is obvious while the side comments one brings a problem of where to draw it on the diagram. The most important consideration here is that the side comment lines must be aligned with the lines in the function prototype. Therefore it was decided to draw it within the function header. It is hard to call this decision the best because it may look as a pollution of the function header space. However this approach covers all the cases of the correct Python code and does not leave space for ambiguities.

To accommodate docstrings the header is extended with one more horizontal section which follows the prototype section.

Return Statement

The flowchart diagrams offer a nice graphics for the return statements and this shape could be used with a minor improvement. Let's take a simple example.

```
def f( x ):
    return x * 154
```

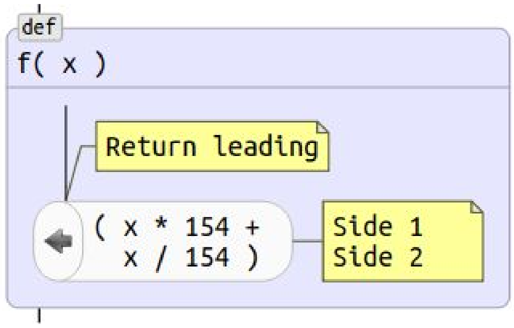


Simple return statement example

The improvement is an icon added to the left part of the primitive. The reason to add the icon is the importance of the return statements from the control flow point of view. The icon serves the eye-catcher purpose even if only a brief look at the diagram was taken.

Similarly to the other language elements the return statements may occupy more than one line and may have both leading and side comments. An example below shows how the suggested graphics can be scaled for such cases.

```
def f( x ):
    # Return leading
    return ( x * 154 +   # Side 1
             x / 154 )   # Side 2
```

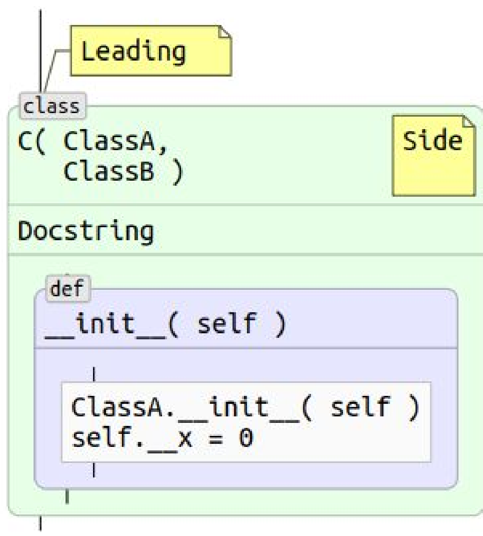


Return statement with comments

Classes

Coming from functions to classes, it seems only logical to use the same idea of scopes for classes. The class graphics layout could be very similar to the function's one with an exception of a background color and a text in the badge. An example below demonstrates a class with comments and a docstring.

```
# Leading
class C( ClassA,    # Side
         ClassB ):
    "Docstring"
    def __init__( self ):
        ClassA.__init__( self )
        self.__x = 0
```

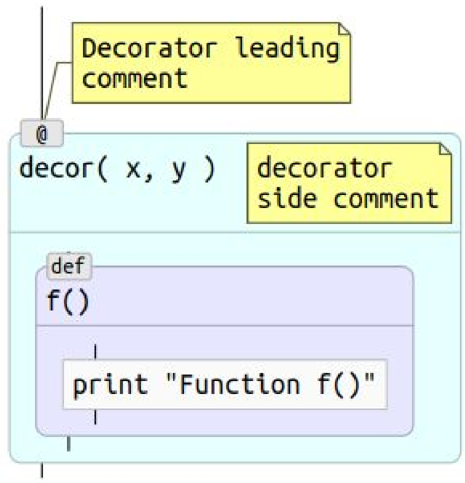


Class graphics

Decorators

One more Python entity which may appear in the context of Python functions and classes is a decorator. Essentially a decorator is a wrapper function so a scope idea could be used for decorators too. To facilitate a quick context identification a distinctive background color and a distinctive badge should be used on the decorators graphic. Here is an example.

```
# Decorator leading
# comment
@decor( x, y )     # decorator
                   # side comment
def f():
    print "Function f()"
```



Decorator with comments

Loops

Python supports two types of loops: for and while. Both of them have a condition, may have break and continue statements inside as well as probably the Python unique else part. The decision of what graphics to use for loops was not an easy one and based on the following considerations.

A traditional flowchart loop primitive is already used to draw the if statements and it seems best to keep it this way because there are no good alternatives for the ifs.

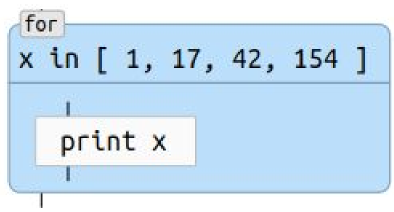
On the other hand a loop has a very definitive point where it begins and where it ends so it reminds a scope for the loop body with a loop condition in the scope header. Another consideration is that the idea of having all actions related to the main purpose of the program on the same vertical line is expressed better in case of a scope primitive. This is because a scope is represented by a closed geometrical figure with the entry on the top and the exit at the bottom. The traditional graphics on the contrary has the entry at the top and the exit on the right.

The next problem with the traditional graphics is that a Python loop may have an else part which does not fit the traditional graphics at all.

The last consideration is the break and continue statements. If a scope primitive is used then the points to where break and continue should lead become very well visible: at the bottom and at the top of the rounded rectangle. Otherwise explicit connectors would be required and it would be hard to draw them automatically without crossing the other primitives or connectors if the loop body is complicated.

The usage of the scope idea for the loops also resolves the question with the location of leading and side comments easily. So it was decided to stick on the scope primitives for Python loops.

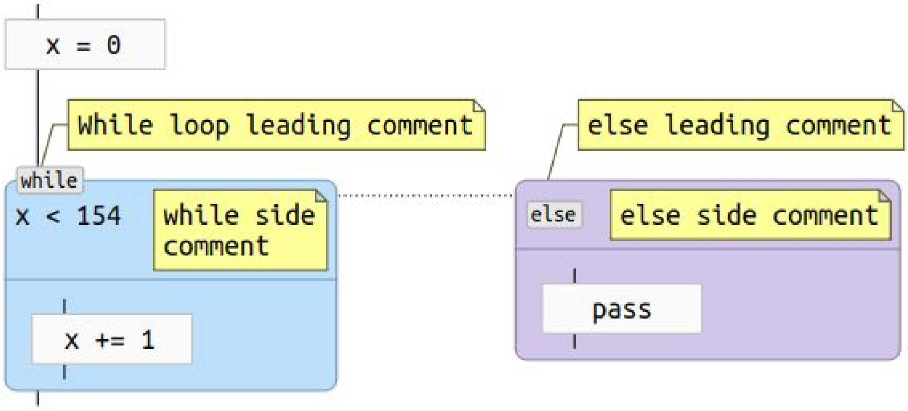
```
for x in [ 1, 17, 42, 154 ]:
    print x
```



For loop

A more elaborated example below features leading and side comments as well as an else part.

```
x = 0
# While loop leading comment
while x < 154:      # while side
                    # comment
    x += 1
# else leading comment
else:               # else side comment
    pass
```



While loop with else part and comments

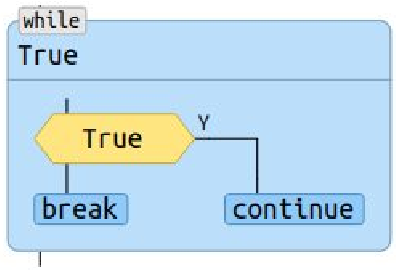
The else part has its own scope and is drawn at the right hand side. To emphasize the association between the loop and the else part the graphics has a dotted connector between the scopes. Both the leading a side comments are shown in a way similar to what was done for the other scopes. The last detail is that the else part badge was moved into the header area because there is nothing to draw there and it seems to look better this way.

Break and Continue

Traditional flowchart diagrams do not offer any graphics for the break and continue statements. These statements correspond to connectors and that introduces a potential problem. Both break and continue statements may have comments tied to them and it would be hard to show comments distinctive enough to highlight that fact. Another problem is that the logic of a loop body could be very complicated and there could be many continue and break statements. In those cases it is very difficult (if possible at all) to draw the connectors with minimum turns and not crossing the other connectors. Usually crossings and excessive number of connectors lead to a diagram which psychologically treated as a messy one and which is difficult to understand. So it would be nice to keep the diagram as clean as possible.

To resolve the problems it was decided to introduce new graphics for the break and continue statements. To highlight that they are essentially jumps to certain points a graphics resembling a label was chosen. It was also decided that the labels would not have an outgoing connectors as a Python developer definitely knows anyway where continue and break will jump to.

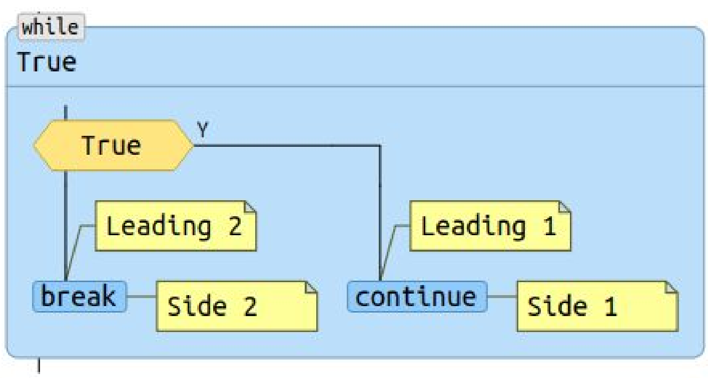
```
while True:
    if True:
        continue
    else:
        break
```



Break and continue

Certainly break and continue could have comments. An example below demonstrates how they could be drawn unambiguously showing what statement they belong to.

```
while True:
    if True:
        # Leading 1
        continue  # Side 1
    else:
        # Leading 2
        break     # Side 2
```

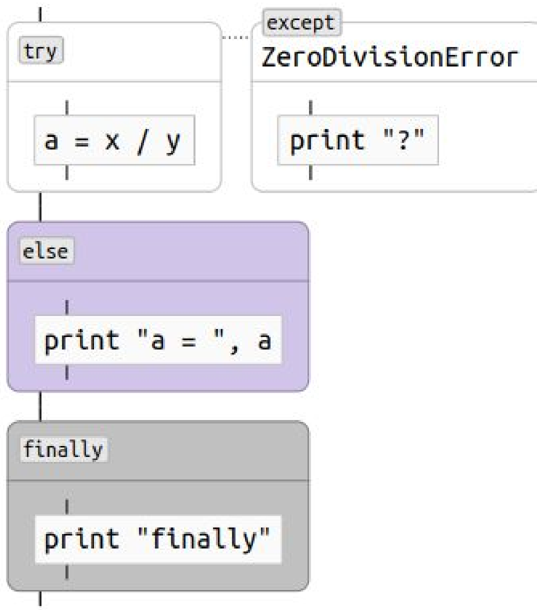


Break and continue with comments

Try, Except, Else, Finally

This is probably the most complicated language statement. It may have try, many except, finally and else blocks. As soon as all these parts have their own suits it was decided to use the idea of a scope for each of them.

```
try:
    a = x / y
except ZeroDivisionError:
    print "?"
else:
    print "a = ", a
finally:
    print "finally"
```



Try-except-else-finally example

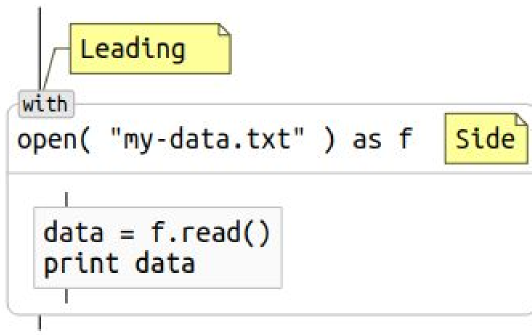
The except scopes are for error handling which are usually not on the main path of a program execution. That is why they are on the right hand side. The else and finally blocks on the other hand are rather on the main line of execution so they are right under the try block. The except blocks have a dotted connector to the corresponding try block. This is done to emphasize the relationships between them. If there are more except blocks, then they will be one after another on the right hand side.

There is not much more to say about the try statement. Obviously each element could have both leading and side comments and if so then the comments will be shown the very same way as for the other statements which use the scope shape graphics.

With

The with statement defines a context in which its suit is executed. Thus the idea of a scope for the with statement looks very appropriate.

```
# Leading
with open( "my-data.txt" ) as f:    # Side
    data = f.read()
    print data
```



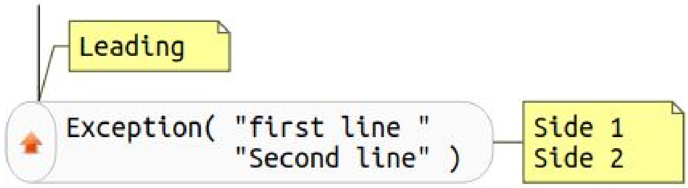
With

Raise

Undoubtedly, an exception generation affects the control flow considerably. So the graphics for it should be identifiable at first glance. The other consideration is that there is a similarity between return and raise statements. Both lead the control flow out of the current scope. So it was decided to use the shape from the return statements and to add a red arrow icon for eye catching purposes.

As usual the raise statement may occupy many lines and may have leading and side comments as shown below.

```
# Leading
raise Exception( "first line "       # Side 1
                 "Second line" )     # Side 2
```



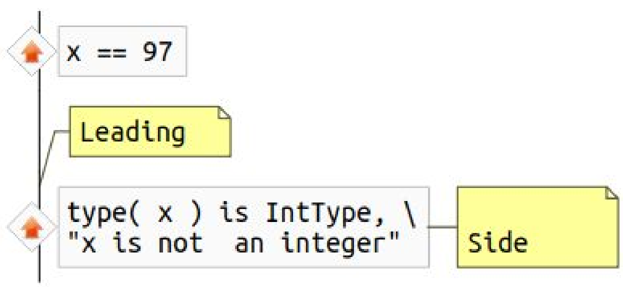
Raise

Assert

Asserts generate exceptions conditionally i.e. they affect the control flow similarly to the raise statements. That is why it seems reasonable to keep the same red arrow icon as the raise statements use but to highlight a conditional nature of asserts.

```
assert x == 97

# Leading
assert type( x ) is IntType, \
       "x is not an integer"  # Side
```



Two assert statements

The conditional nature of the assert statements is shown via a diamond shape on the left which shares the icon with the raise statements. Certainly asserts may have leading and side comments and this case is covered by the second statement in the example above.

sys.exit()

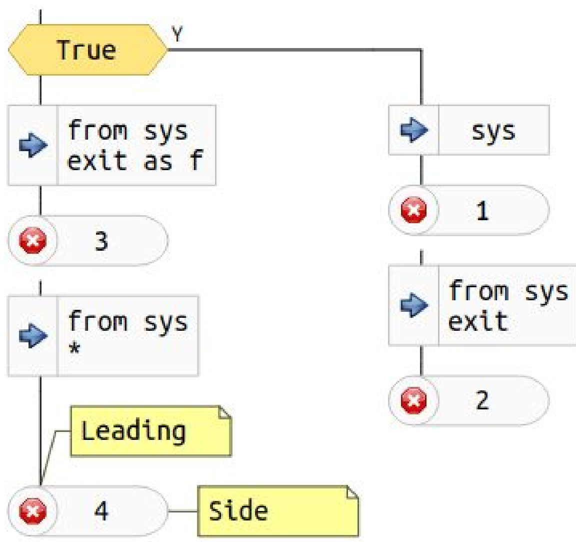
Strictly speaking the sys.exit() call is not a part of the language but a library function. It however affects the control flow no less than exceptions and probably even severer. So the idea of recognizing the sys.exit() calls and highlight them explicitly looks attractive and valuable.

A peculiar detail here is that the sys.exit() could look different depending on how the corresponding import is done. An example below demonstrates the suggested graphics and various ways to import sys.exit().

```
if True:
    import sys
    sys.exit( 1 )

    from sys import exit
    exit( 2 )
else:
    from sys import exit as f
    f( 3 )

    from sys import *
    # Leading
    exit( 4 )     # side
```



sys.exit() example

Of course there is a possibility to call sys.exit() through the eval("...") call as well and it is very difficult (if possible at all) to cover this case. In practice however handling the most common cases is better than nothing.

The sys.exit() call prematurely finishes the program execution i.e. could be considered as a return which passes by all the intermediate levels. So the graphics shape for sys.exit() is borrowed from the return statements with a specific icon which reflects the nature of it.

File

The last required primitive is for a file. A Python file has a few attributes which should be shown. Namely, a file may have:

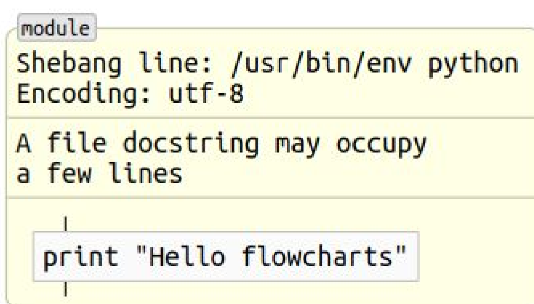
- a docstring
- an encoding line
- a hash bang line

Naturally, a file forms a scope within which all the other items are located. So a scope primitive could be used once again.

```
#!/usr/bin/env python
# encoding: utf-8

"""
A file docstring may occupy
a few lines
"""

print "Hello flowcharts"
```



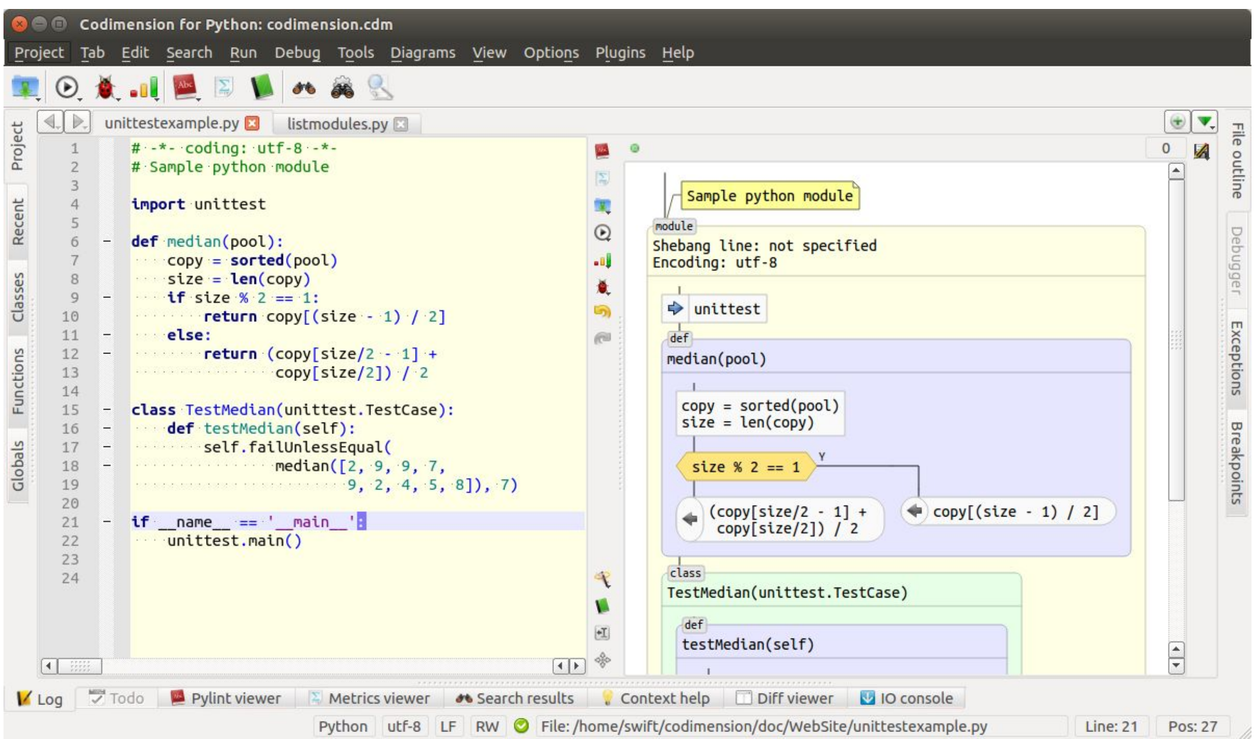
Python file

Proof of Concept: Codimension Python IDE

So, having a good idea of what information should be collected from a source code and how to draw it, a tool development can be started. An important question at this stage is as follows: how the text and the graphics should collaborate with each other? One of the options is to support graphics only. This way was rejected because of two major reasons. The first is that it is easy to imagine both situations when graphics wins over text and vice verse. The second reason is that all the typical IT projects infrastructure is tied to text, e.g. tools to compare between revisions, various search tools etc.

Therefore, the tool should support both ways of the program representation - via text and via graphics - without sacrificing one of them. In a usual IDE a text editor occupies the main area so now this area is going to be equally divided between text and graphics.

Before starting a new project an analysis of existing open source IDE took place. The idea was to consider development of a plugin - in opposite to developing a whole tool - which adds graphics capabilities to an existing project. Unfortunately nothing suitable was found. So a new experimental project called [Codimension Python IDE] was started.



Common view

Codimension was not started from an absolute scratch. Some ideas and code have been taken from another open source Python IDE called [Eric 4].

At the moment Codimension implements an automatic drawing of a flowchart diagram for an arbitrary Python (series 2) code. A pause in typing code is detected and the diagram is automatically re-drawn on the right hand side. If the code becomes broken at some stage, the diagram is simply not updated and an indicator on the top tells about the current state.

Also a feature of showing a navigation-like path for a scope under the mouse cursor is implemented. A double click on the diagram is also supported: the focus is passed to the text editor part and the corresponding line is set as the current one. The opposite way of synchronizing the views is supported via a hotkey combination. When the user invokes it the IDE detects what graphics primitive corresponds to the current line in the text editor and scrolls the graphics view appropriately. The features of zooming and exporting to an SVG, a PDF and a PNG are implemented as well. Obviously, not all the IDE features are mentioned here and more features are planned for the graphics view.

Now, let's talk about the implementation details.

General Information

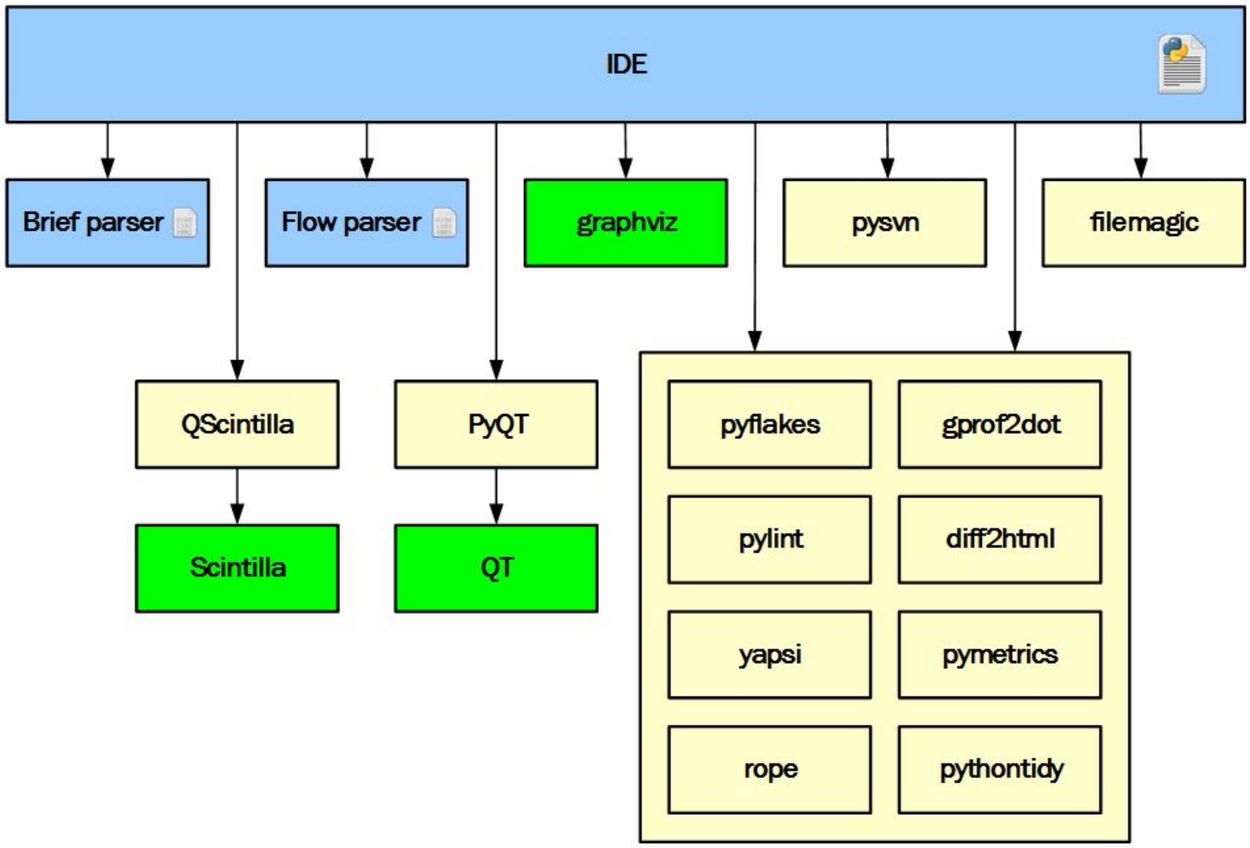
Codimension is implemented as an open source project licensed under GPL v.3 and its source code resides in three repositories on github: two Python extension modules cdm-pythonparser and cdm-flowparser plus the IDE. The extension modules are mostly written in C/C++ while the IDE is written in Python 2. The UI is implemented using Python QT library bindings - PyQT.

The development is done on Linux and for Linux. In particular Ubuntu distribution was used most of the time.

The IDE targets projects written in Python 2.

Architecture

The diagram below shows the most important components of the IDE.



IDE architecture

Blue highlights the parts developed within the Codimension project. Yellow is used for third party Python written modules and green denotes third party binary modules.

It was obvious from the very beginning that one developer is not able to develop all the required components from scratch within the reasonable timeframe. Therefore the existing Python packages were used where it was possible and reasonable. The diagram above reflects this approach quite well.

Only three parts are developed for the project. The IDE is written in Python to speed up the development and to make it easier to experiment. The extension modules are written in C/C++ to have a better performance. The purpose of the brief parser is to report all the entities found in a Python file (or a buffer), e.g. imports, classes, functions, global variables, docstrings etc. This information lets to implement features like:

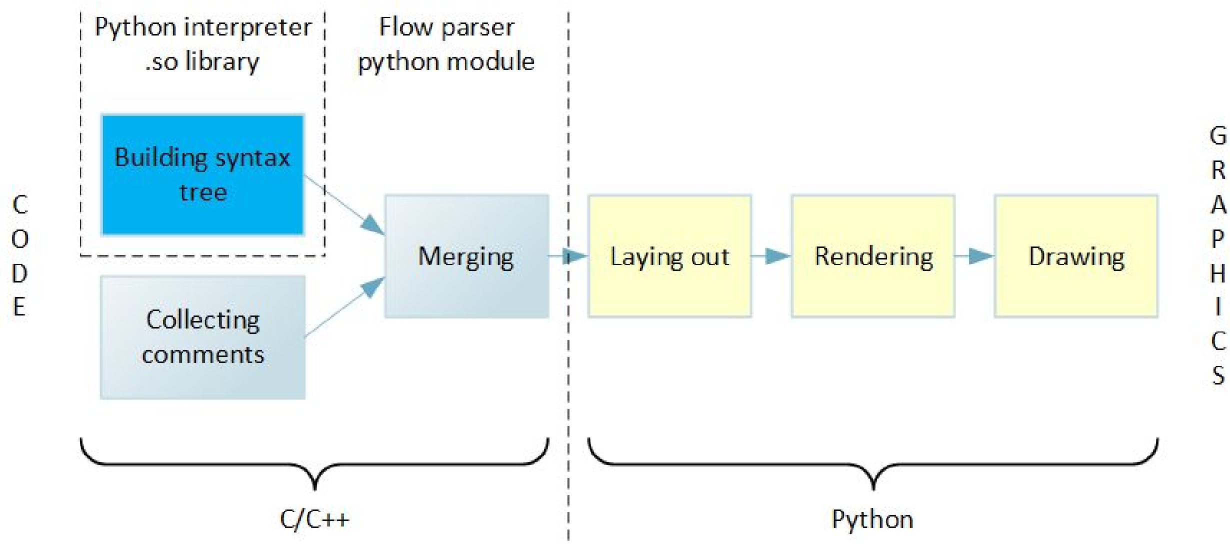
- A structured view of a file content and navigation through it
- Analysis of defined but never used global variables, classes and functions
- etc.

The flow parser purpose is to provide a Python file (or a buffer) content in a way convenient for drawing a diagram.

All the other components are third party. The PyQT bindings were used for the UI and network parts. QScintilla played the role of a text editor component and also was used in a redirected I/O console and in an SVN blame widgets. Graphviz was used to calculate graphics layout of a dependency diagram and some others. Also many third party pure Python packages were used: pyflakes, pylint, filemagic, rope, gprof2dot etc.

Code to Graphics Pipeline

An implementation of the transition from text to graphics is built as a pipeline. Each stage of the pipeline is responsible for a certain piece of work and the results are passed to the next stage. A diagram below shows all the pipeline stages. The input - a text - is on the left hand side and the output - a graphical representation - is on the right hand side.



Code to graphics pipeline

The process starts with parsing the source code into a syntax tree. Then the syntax tree is analyzed and all the code blocks, functions, classes etc are created as a hierarchical data structure. Then there is another pass over the source code to collect comments. After that the comments and the recognized language elements are merged into a single data structure. The merge is done because it is more convenient to have comments already associated with the corresponding language elements on the further stages. The described above actions are done in a flow parser Python module which is written in C/C++ to achieve the best possible performance.

The further stages are written in Python and reside in the IDE. This allows better flexibility and ease of experimenting in comparison to a C++ implementation.

At the beginning all the recognized elements are laid out in accordance to the flow parser output in a data structure called a virtual canvas. After that the virtual canvas goes through rendering. And finally all the graphics elements are drawn on the screen appropriately.

Let's discuss all these stages in details.

Syntax Tree

This is the very first stage on the way from text to graphics. The purpose of the stage is to parse the source code and to build a hierarchical data structure which represents the text. Building a syntax tree and then walking it helps to make the implementation of the stage easy. Obviously there was a wish not to develop one more Python parser specifically for the project but to use one already developed. Fortunately, the Python interpreter shared library has a suitable function. It is a C function which builds a syntax tree in memory for the specified Python code. To make the tree easy to analyze a utility which prints the tree nodes was written. Here is an example of a source code and its syntax tree.

```
#!/bin/env python
# encoding: latin-1

def f():
    # What printed?
    print 154
```

The following tree is built (fragment only to avoid polluting):

```
$ ./tree test.py
Type: encoding_decl line: 0 col: 0 str: iso-8859-1
  Type: file_input line: 0 col: 0
    Type: stmt line: 4 col: 0
      Type: compound_stmt line: 4 col: 0
        Type: funcdef line: 4 col: 0
          Type: NAME line: 4 col: 0 str: def
          Type: NAME line: 4 col: 4 str: f
          Type: parameters line: 4 col: 5
            Type: LPAR line: 4 col: 5 str: (
            Type: RPAR line: 4 col: 6 str: )
```

```
          Type: COLON line: 4 col: 7 str: :
          Type: suite line: 4 col: 8
            Type: NEWLINE line: 4 col: 8 str:
            Type: INDENT line: 6 col: -1 str:
            Type: stmt line: 6 col: 4
            . . .
```

Each line of the output corresponds to a tree node and the nesting level is shown via indentation. Also all the collected node information is shown.

Generally the tree looks nice: there are line and column numbers, the node types correspond to the formal Python grammar specification. However there are some problems too. First, the source code had comments but the tree has no information about them. Second, the encoding line and column information does not reflect the reality. Furthermore, the source code had latin-1 encoding but the syntax tree reports iso-8859-1. In case of multiline string literals there is a problem as well: the tree has no information about line numbers. All these surprises had to be taken care in the module implementation. It however seems a minor obstacle in comparison to the complexity of a full fledged parser.

The flow parser module defines types which will be available in the Python code on the further stages. The types correspond to all the recognized language elements, e.g. Class, Import, Break etc. Each type has some specific attributes in addition to the common properties: all the types basically describe elements in terms of fragments: where a piece of text starts and where it ends.

The formal output of the tree walking stage is an instance of the ControlFlow class which has all the recognized elements stored hierarchically.

Collecting Comments

Due to the fact that the comments are not in the syntax tree (obviously, the Python interpreter does not need them) but they are needed for a lossless representation of the code, another pass over the source code is required. The pass collects information about each line of the comments. It is quite easy to do thanks to a simple Python grammar and an absence of multilined comments and a preprocessor.

The comments are collected as a list of fragments where each fragment describes one line of a comment via a set of attributes: line and column numbers of the start and the end of the comment as well as their absolute counterparts.

For example, the code:

```
#!/bin/env python
# encoding: latin-1

def f():
    # What printed?
    print 154
```

Has three comment fragments:

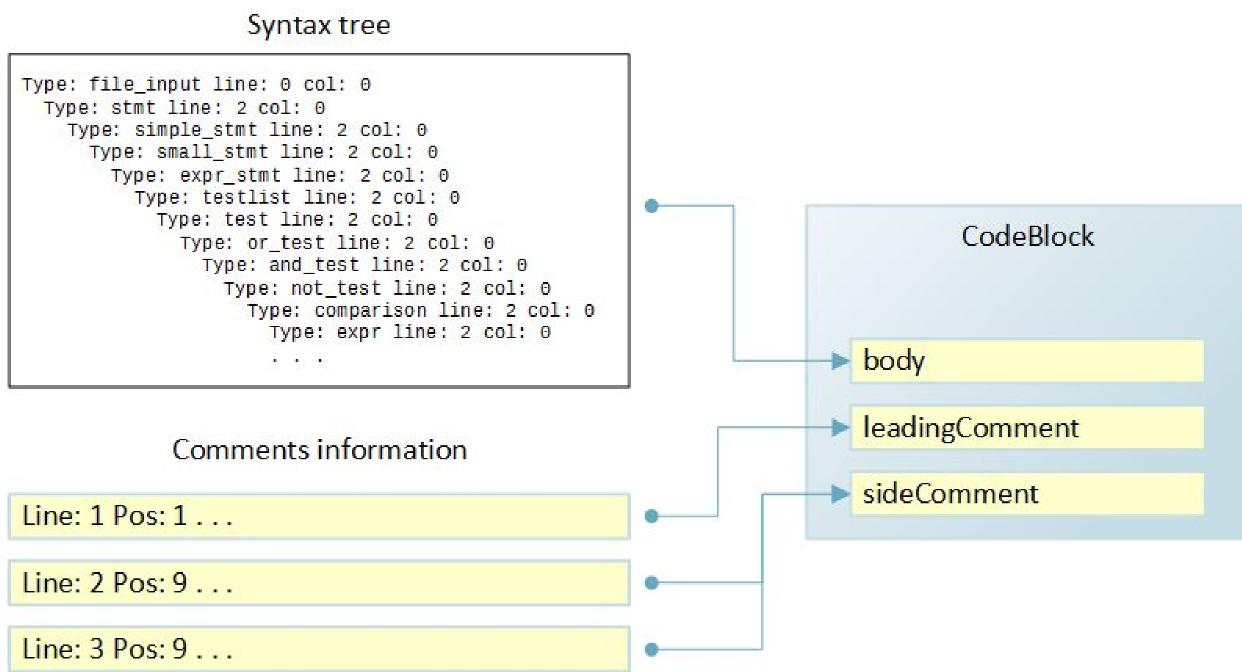
```
Line: 1 Pos: 1 ...
Line: 2 Pos: 1 ...
Line: 5 Pos: 5 ...
```

Merging Comments with Code

At this moment of the pipeline there are two data structures populated: a control flow and a list of comments. However when a diagram is laid out it is more convenient to have one merged data structure because the recognized elements and their comments are tightly coupled. So the extension module has a phase of merging the comments and the control flow structure.

Let’s take an example:

```
# leading comment
a = 10  # side comment 1
        # side comment 2
```



Merging comments with code

A syntax tree walk for the code in the example will in particular produce an instance of the CodeBlock class. The class instance has among the others the body, leadingComment and sideComment attributes which describe the corresponding elements in terms of fragments. The body attribute is filled by the information from the syntax tree while the comment fields are filled with None initially.

A comment collecting pass for the code in the example will produce a list of three fragments. During the merging procedure the first fragment is used to populate the leadingComment attribute while the second and the third fragments are used for the sideComment attribute. The merge is done basing on line numbers available from both sources.

So the output of the merging stage is a fully populated hierarchical data structure which describes a file or a buffer content without any information loss.

Module Performance

The pipeline stages described above are written in C/C++ and packaged into a Python extension module. The idea was to achieve the best possible performance to avoid irritating delays when a diagram is redrawn which happens in pauses of typing. To test the performance the module was run on the platform at hand:

- Intel Core i5-3210M laptop
- Ubuntu 14.04 LTS

To process all the files from a standard Python 2.7.6 installation. Having 5707 files it took around 6 seconds. Certainly the file sizes differ and the parsing time depends on the size however an average result of about 1 ms per file on not the best ever equipment is more than acceptable. In practice the text which needs to be parsed is already in memory and it reduces the processing time too.

Laying Out on a Virtual Canvas

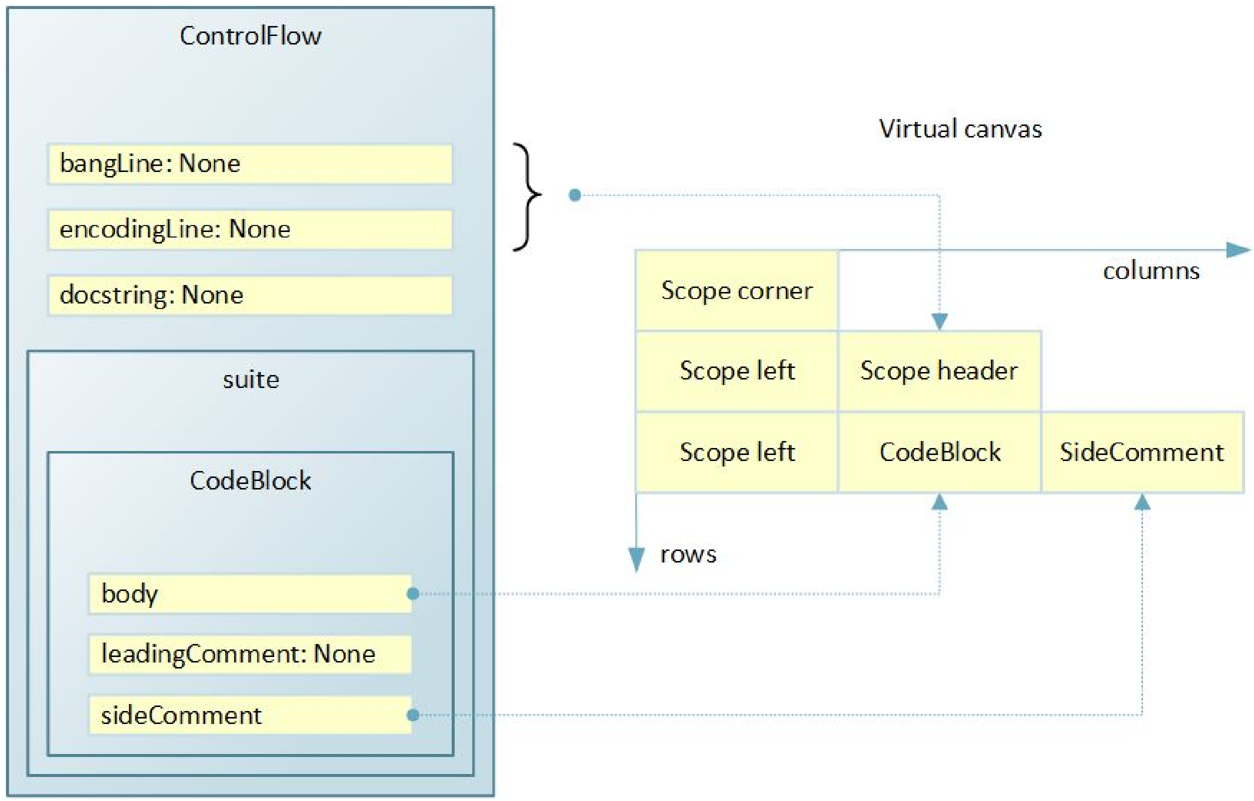
The purpose of this pipeline stage is to allocate all the required elements on a virtual canvas respecting the relationships between them. A virtual canvas can be imagined as a surface with rectangular cells. A cell can be empty or have one graphics element or have a nested virtual canvas. At this stage the only location of the elements is important but not their precise sizes.

A canvas does not features a fixed size and can grow down and right as needed. This approach corresponds to the prepared data structure and the way a diagram is drawn. The process starts from the upper left corner. New rows and columns are added as needed. For example, when a new code block is processed a new row will be created. If the block has a side comment then a new column will be added to the row.

A set of graphics elements used for the virtual canvas cells nearly matches the set of the language recognized elements. A small extension of the set is required: e.g. the canvas may need a connector going from top of the cell to the bottom of it while there is no such item in the language.

An implementation of a virtual canvas uses a list of lists (two dimensional array) which is empty at the beginning. Let’s take a simple example to illustrate how the process works.

```
a = 10    # side comment 1
          # side comment 2
```



Allocation of graphics elements on a virtual canvas

The figure above shows a data structure on the left which was formed as a result of the code analysis. An instance of the ControlFlow class has a few attributes and a container suite which in turn holds one element - an instance of the CodeBlock class.

Initially the canvas is empty and the process starts. As it was discussed earlier a module will be drawn as a scope i.e. as a rounded rectangle. To make the further graphic element size calculation easier a scope rectangle is split into pieces: corners and edges. At the top left corner of the diagram there will be a module scope rectangle corner so a row is added to the canvas and then a column is added to the row, setting the cell value to ‘scope corner’. There is no need to allocate the top edge of the module scope rectangle because the vertical spacing for the elements below is provided by the corner element and when it comes to actual drawing the whole rounded rectangle will be drawn at the moment its top left corner is found.

The next step is to process the module header. The module has a hash bang and an encoding lines. The values of the corresponding attributes in the example are None but the header needs to be drawn anyway. So a new row is added to the canvas. The header needs to be drawn within the scope rectangle with some spacing so the first cell in the row could not be allocated for the module header. The first cell must be designated for the left edge of the scope rectangle and the second cell will hold the header. The right edge of the scope rectangle does not need to be allocated because of two reasons. First, at this moment it is unknown how many columns there will be in the widest row. Second, the whole scope rectangle will be drawn when its left corner is found.

The module could have a docstring and in this case another row would be allocated. The example however does not have it so the process goes to the suite container. The first item in the container is a code block. So a row is added and two columns are allocated respectively for a scope left edge and a code block. The example features a side comment for the code block so another column needs to be allocated to the right and set to a SideComment element.

There are no more elements in the suite container so the population of the virtual canvas content is over. A bottom left corner and a bottom edge of the module scope could be skipped because of the reasons similar to the described above. The omitted elements just need to be considered when the sizes are calculated.

Rendering

The purpose of this stage is to calculate the sizes of all the graphics elements which will be drawn on the screen. It is done via visiting all the allocated cells, calculating sizes and string the calculated sizes in the cell attributes.

Each cell has two widths and two heights: minimally required and actual measurements which in turn may depend on neighbour cells.

Let’s first discuss how height is calculated. It is done on per-row basis. Let’s take the second row where a code block is allocated. The assignment takes one text line while a side comment occupies two text lines. Thus the cell with the comment will need more vertical pixels when it is drawn. On the other hand all the cells in a row needs to be of the same actual height to avoid shifting the cells below. Therefore a simple algorithms could be used: walk all the cells in a row and calculate individual minimally required height. Then take the greatest minimal height and use it as an actual height for all the cells in the row.

The story with the cell width is a bit more complicated. From this perspective there are two kind of rows:

- Those with cell widths which need to be calculated respecting the cell widths in a neighbour row
- Those with cell widths which could be calculated independently from the other rows

A good example of the first kind of rows is an if statement. The branch which is drawn below the condition primitive could be of an arbitrary complexity and consequently of an arbitrary width. The other branch needs to be drawn on the right and also requires a connector located in a row above. So the width of a cell with the connector needs to be calculated considering the width of the rows below.

The widths of the cells in independent rows are calculated as a single pass and an actual width matches the minimal required.

For the dependent row regions the rendering procedure is more complicated. First the minimal required width is calculated for all the cells in the region. Then for each column the actual width is taken as a maximum of the minimum required of all the cells in the column. Generally the process is similar to what is done for the height calculation in a row.

The calculations are done recursively for the nested virtual canvases. Also the calculated sizes respect various settings: font metrics, text padding, spacing etc. When the rendering stage is completed there is everything ready for drawing on the screen.

Drawing

The drawing stage is very simple. Since the implementation uses the QT library a graphics scene is created of the size calculated on a previous stage. Then a recursive visiting of all the cells in a virtual canvas is done and for each cell a graphics scene item is added respecting the sizes and location.

The process starts from the top left corner and the current coordinates are set to 0, 0. The cells in a row are visited and after each cell is processed its width is added to the current x coordinate value. When a row is over, the x coordinate is reset to 0 and the row height is added to the current y coordinate value.

At this moment the graphics representation of the code is drawn on the screen and ready to use.

Present and Future

Now it is time to discuss what functionality has already been implemented and what could be added in the future.

The list of what has been done is quite short:

- Automatic diagram updates in pauses of typing
- Manual synchronization of the visible text and graphics in both directions. If an input focus is in a text editor and a hotkey is invoked then the IDE searches a graphics primitive which corresponds to the current text cursor position and scrolls the diagram appropriately. Then the primitive is highlighted. The opposite synchronization direction is

done via handling a double mouse click on a primitive which leads to the corresponding line of code in the text editor.
- Diagram scaling. The current implementation uses the QT graphics scene scaling feature however it is planned to replace it with scaling through changing the font size.
- Exporting diagrams into PDF, PNG and SVG. The quality of the export is defined by the QT library implementation.
- Current scope navigation panel. The graphics uses the idea of a scope intensively so a typical diagram would have many nested scopes. A navigation panel shows a path to the scope under cursor in terms of nested scopes.
- Individual switching branch location for the if statements. By default the N branch is drawn below while the Y branch is drawn on the right. The diagram lets to switch the branches location using a context menu item.
- Individual replacement of a text in any of the graphics primitives. Sometimes there is a need to replace a certain primitive text with something else. For example a condition in terms of variables and function calls could be long and not obvious while a natural language phrase could describe the situation better. The diagram lets to replace the displayed text with an arbitrary one and show the original one in a tooltip.
- Individual replacement of colors for any graphics primitive. Sometimes it is a good idea to draw an attention to a certain piece of code via highlighting it with a distinctive color. For example a potentially dangerous part of code can be highlighted in red or a set of blocks responsible for a common functionality can be highlighted with a common background. The diagram lets to change the colors of a background, a foreground and an outline of a primitive.

The practice shows that the usage of the already available functionality can change the diagram appearance considerably.

The features that could be added to the existing basis are limited only by the fantasy. So the only most obvious are mentioned below.

- Automatic synchronization of the text and graphics views when they are scrolled
- All the editing operations could be supported on the graphics view so that when something is changed on the diagram the text view is updated correspondingly. This could include editing text within primitives, deleting, copying and pasting blocks.
- Support operations on a group of the primitive.
- Visualization of the debugging on the diagrams
- Search support for the diagrams
- Printing support
- There could be controls which allow to show or to hide various elements: comments, docstrings, classes and functions and loops bodies etc. And when they are hidden then the actual content could be shown in tooltips.
- Highlighting different kind of imports: system imports, project imports, unknown imports.
- Support of additional non-python blocks or pictures on the diagrams

- Smart scaling. It is possible to introduce a few fixed scale levels: all items, all but comments and docstrings, only class and function headers, dependencies between files in the current directories with a highlight of the external dependencies. If these levels are bound to a mouse wheel with a modification key then a general information could be retrieved very quickly.
- Grouping many blocks into a single graphics primitive and ungrouping them back. A group of blocks which are responsible for a common functionality can be selected on the diagram and replaced with a new primitive with a provided text on it. The only natural limitation here is that the group should have one entry and one exit. This functionality can be useful when an unknown code is analyzed. When the reader understands what a group of blocks does the complexity of the diagram can be reduced via grouping a few blocks and replacing them with a single element. For example a new element could have a title “MD5 calculation” instead of a few original blocks. Obviously at any moment a group could be expanded to see all the details. This feature can be considered as adding a third dimension to the diagram.

CML v.1

The features mentioned in the previous section could be split into two groups:

- Features which do not depend on the code
- Features which require to store information related to the code related

Here is a good example of a feature which has no relation to the code: scaling a diagram. The current scale factor is rather an IDE setting but does not depend on a certain piece of code.

On the other hand switching the branches location for an if statement is linked to a certain statement so an information about this connection needs to be saved. Naturally, when the user opens the very same file two days later the branches have to be drawn as it was instructed earlier.

Obviously there are at least two approaches of where to store an auxiliary information. It could be stored directly in a source code file or in a separate file or even in many auxiliary files. When a decision was made the following considerations were taken into account:

- Let’s imaging a large project with many developers who are working on the same code. It is quite possible that some of them like the graphics code representation and use it often while the others use only vim for their editing needs. In this case if the auxiliary information is stored in separate files then it is quite difficult to maintain consistency of two sources. The probability that the consistency is broken at some stage becomes very high.

- If the approach of additional files is chosen then they may pollute the project files namespace and it requires more efforts when it comes to saving changes into a revision control system.
- When a developer adds some kind of markup on the diagram - for example, replaces a complicated condition with a suitable phrase in English - it is usually done not for fun but to make the program clearer. Generally the changes have a value and thus it would be nice to keep that value available even for those who have not discovered the graphics representation yet.

These considerations lead to a conclusion: if there is a compact solution to store the additional markup information directly in the the source files then it is preferably to go this way. Such a solution was found and called CML: Codimension Markup Language.

CML is a micro markup language which uses Python comments. Each CML comment consists of one or more adjacent lines. A first line format is as follows:

```
# cml <version> <type> [key=value pairs]
```

A format of the further lines is as follows:

```
# cml+ <continue of the previous CML line
```

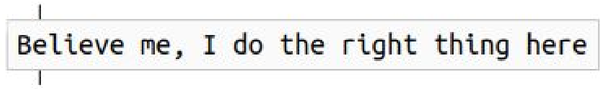
The ‘cml’ and ‘cml+’ literals distinguish a CML comment from all the other comments. A version field is an integer and introduced for the future extensions if CML evolves. A type defines what exactly will be done when a diagram is drawn. A type is a string identifier, e.g. ‘rt’ (stands for ‘replace text’). Key=value pairs in turn let to have an arbitrary number of arguments for the CML comments.

The chosen format is very simple and can be read by a human easily. So the requirement to make an auxiliary information available for text-only users is covered. The only not enforced convention between the team members is not to break CML comments.

CML: Text Replacement

The recognition of the CML comments for text replacement has already been implemented. These comments may appear as a leading comment for any recognized language element. Here is an example:

```
# cml 1 rt text="Believe me, I do the right thing here"
False = 154
```



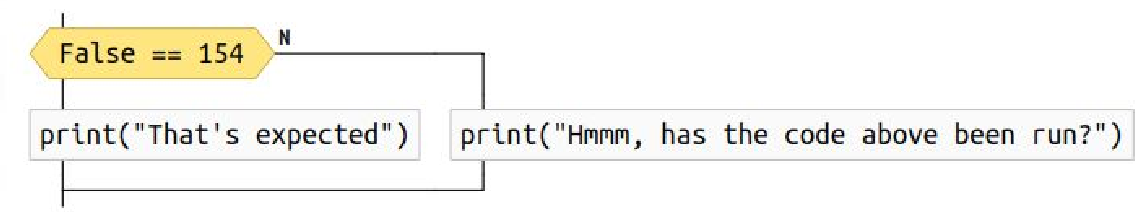
Code block with a replaced text

So far there is no support of the comment on the graphics pane. At the moment such a comment could be added only from a text editor. The ‘text’ parameter purpose is most probably obvious, while the comment type ‘rt’ is chosen as a short for ‘replace text’.

CML: Switching If Branches

The recognition of the CML comments for switching if branches has already been implemented too. There is a support on both, via a text editor and via a graphics pane. A mouse context menu on a diagram has an option to switch the branches. Upon selection of the option an appropriate text will be inserted into the source code and the diagram will be redrawn.

```
# cml 1 sw
if False == 154:
    print("That’s expected")
else:
    print("Hmmm, has the code above been run?")
```



If statement with the N branch on the right

If there was no CML sw comment for the if statement in the example above then the Y branch would be shown on the right.

The comment does not need any parameters and its type ‘sw’ is chosen as short for ‘switch’.

CML: Custom Colors

The recognition of the CML comments for changing graphics elements colors has already been implemented. It may appear as a leading comment for any recognized language element. Here is an example:

```
# cml 1 cc background="255,138,128"
# cml+ foreground="0,0,255"
# cml+ border="0,0,0"
print("Danger! Someone has damaged False")
```

Block with individual colors

The comment can override a background color (parameter ‘background’), a font color (parameter ‘foreground’) and a border color (parameter ‘border’). Its type ‘cc’ stands for ‘custom colors’.

So far there is no support of the comment on the graphics pane but a full support via text is in place.

CML: Grouping Items

There is no support of this CML comment at the moment neither via text nor via graphics. It is however clear how it could be implemented.

The sequence of events could be as follows. The user selects a group of items on a diagram. The selected group must have one entry and no more than one exit. Then the user invokes a context menu and selects an option to group items. A dialog appears to enter a text for a new graphics item. When the input is confirmed the diagram is redrawn so that instead of the selected items one item appears and the text in it is what the user provided.

Obviously the selected group as a separate entity has two points in the code: where it starts and where it ends. So CML comments could be inserted at these points to mark them, for example:

```
# cml gb uuid="..." title="..."
. . .
```

```
# cml ge uuid="..."
```

Here the ‘uuid’ parameter is automatically generated at the moment the group is created. The parameter is used to properly identify the groups pairs because there could be nested groups. The purpose of the ‘title’ parameter is obvious and the comment type identifiers are chosen as shorts for ‘group begin’ and ‘group end’ respectively.

The ‘uuid’ parameter also allows to detect various problems. For example one of the comments in a pair could be accidentally removed. Another example of the ‘uuid’ parameter usage is memorizing the groups which should be shown as expanded (or collapsed) when a file is opened in the IDE next time.

Side Effects

The practice of using Codimension revealed that the technology has a few interesting side effects which were not predicted at the design and development time.

First, it turned out that the generated diagrams suit well for the documentation and for discussions with colleagues who are not familiar with programming but are experts in an application area. In these cases a pseudo code not purposed for the execution was prepared. The code followed a formal python syntax and the purpose was to highlight the essence of the algorithm. Then the generated diagram was inserted into a documentation or simply printed to be used as a discussion handout. It was especially easy to make changes in the algorithm - a diagram is redrawn momentarily after changes in the text without manual changes in graphics.

Second, an interesting psychological effect was noticed. A developer used Codimension IDE to open a code which was written some time ago and noticed that the diagram looks too messy. So to get a nicer looking diagram the developer made changes in the original code. In fact it was a refactoring which simplified the code and thus improves the overall quality. Also it simplifies the further support of the code regardless whether it is the very same developer or someone else.

Third, in spite of the fact that the development is done for Python, the technology can be applied to other programming languages as well. Python was chosen for experiments because of a few reasons: it is a popular language with a simple formal grammar.

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