BlackHat Asia 2024 / rocky@gnu.org

`uncompyle6` and `decompyle3`: How to Read and Write a High-Level Bytecode Decompiler

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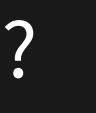
Rocky Bernstein

Slide text: https://rocky.github.io/blackhat-asia-2024-additional/all-notes-print

Survey

Survey

- How many people have used 

,  , or  ?

Survey

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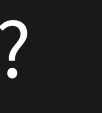
,  , or ?
- How many people have used the above to decompile *Python* bytecode?

Survey

- How many people have used  ,  , or  ?
- How many people have used the above to decompile *Python* bytecode?
- How many people have used `uncompyle6`, or `decompyle3`?

Github commit statistics for `uncompyle6`

I am the current maintainer and developer of `uncompyle6`, and `decompyle3`.

So, who *am* I?

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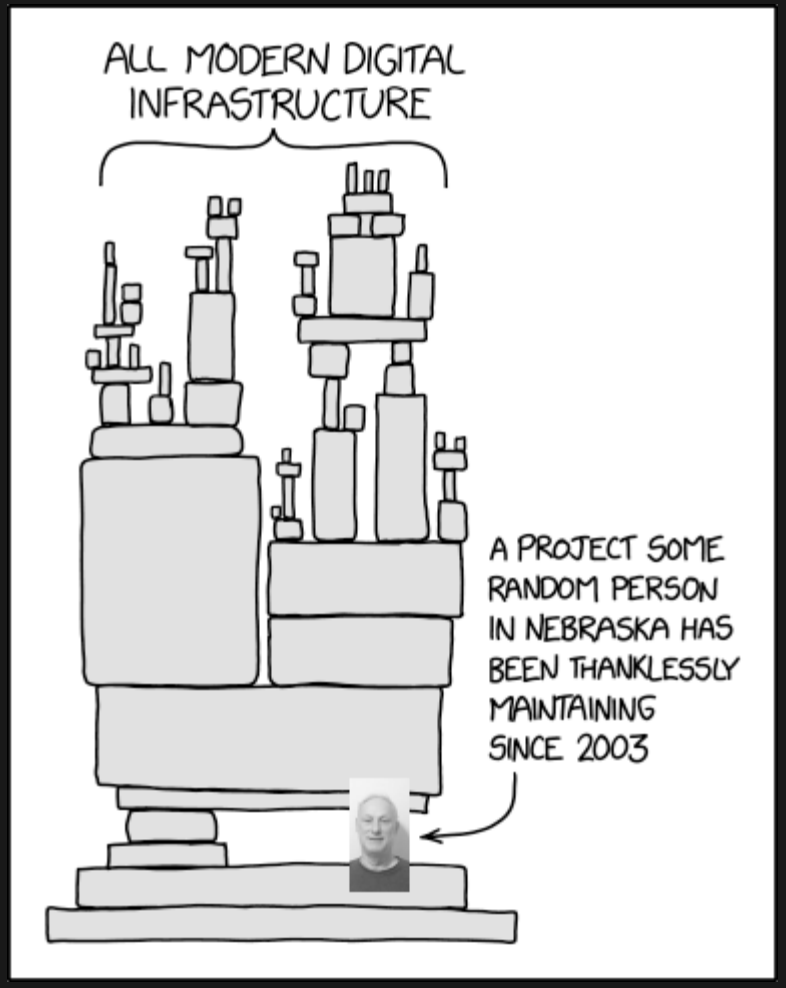

https://xkcd.com/2347/

Some Open Source Software that Includes My Code:

Background

- High-level bytecode is attractive for malware writers

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- Decompilers are not new, but ....

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Background

- High-level bytecode is attractive for malware writers

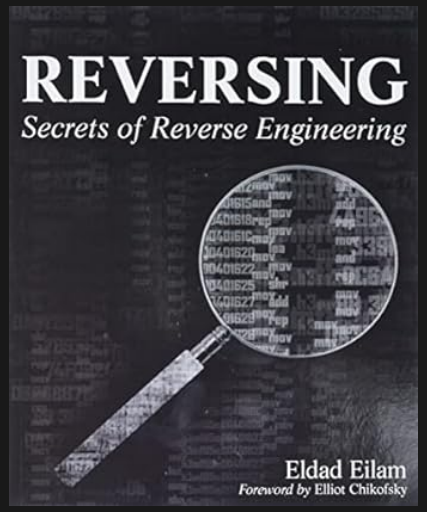
- Decompilers are not new, but ....
- Ideas presented here are new.
- "General-purpose" Decompilers
- Bytecode Decompilers (Special Purpose)

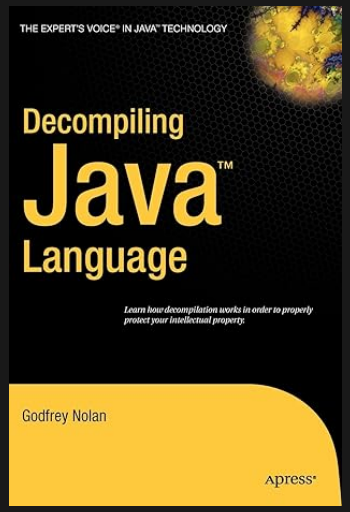
Theory and books on *making* compilers:

... (40 others)

Books on making *de*compilers:

Books on making *de*compilers:





Can AI Save the Day?

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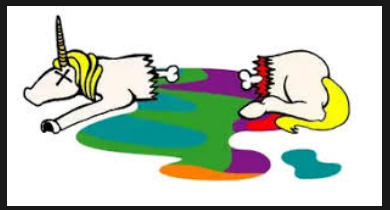
Not yet.



Decompilation in the World of High-Level Bytecode

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- Raise awareness of the differences between "General Purpose" decompiling and High-level Bytecode Decompiling

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- Introduce Decompilation as a Language-Translation problem.

Decompilation in the World of High-Level Bytecode

- Raise awareness of the differences between "General Purpose" decompiling and High-level Bytecode Decompiling
- Introduce Decompilation as a Language-Translation problem.
- Introduce Decompilation as a Compilation Process.

Key Takeaways

- Understand more about what is wrong when something goes wrong with decompilation.
- Understand the difference between *disassembly* and *decompilation*.
- Begin to see the difference between *machine code* and *high-level bytecode.*
- Understand the some limits of Python decompilation and decompilation in general.

Simple Python Program

In file `five.py`:

```
"""
BlackHat Asia Example
"""


def five():
    """Returns the string five"""
    return "5"


# Call the function we just defined.
print(five())
```

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$ python five.py
5
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```
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5
```

Instruction bytecode of main program:

```
  0 |64 00 5a 00 64 01 64 02 |
  8 |84 00 5a 01 65 02 65 00 |
 16 |83 00 83 01 01 00 64 03 |
 24 |53 00                    |
```

Byte-Compiling Python

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Byte compile this program:

```
1 $ python -m compileall five.py
2 Compiling 'five.py'...
3 $ ls -l __pycache__/five.cpython-38.pyc
4 -rw-rw-r-- 1 rocky rocky 301 Feb 17 10:16 __pycache__/five.cpython-38.pyc
```

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I run the bytecode:

```
$ python /tmp/five-moved.pyc
5
```

and again I get 5.

Python Bytecode Decompilation Example

```
$ uncompyle6 /tmp/five-moved.pyc
# uncompyle6 version 3.9.1
# Python bytecode version base 3.8.0 (3413)
# Decompiled from: Python 3.12.2 (main, Feb 14 2024, 04:48:40) [GCC 13.2.0]
# Embedded file name: five.py
# Compiled at: 2024-02-17 10:16:08
# Size of source mod 2**32: 153 bytes
"""
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def five():
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print(five())
# okay decompiling /tmp/five-moved.pyc
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Source Code Differences

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4. Abstract the Parse Tree into an Abstract Syntax Tree

How These Decompilers Work

Decompilation processed in a pipeline of these phases:

1. Get bytecode disassembly via xdis
2. Tokenize or "lift" the disassembly
3. Parse tokens into a Parse Tree
4. Abstract the Parse Tree into an Abstract Syntax Tree
5. Produce Source from the Abstract Syntax Tree

Disassembly using `pydisasm` from xdis

```
$ pydisasm /tmp/five_moved.pyc
```

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```
$ pydisasm /tmp/five_moved.pyc
```

```
 1 # pydisasm version 6.1.0
 2 # Python bytecode 3.8.0 (3413)
 3 # Disassembled from Python 3.8.18 (default, Sep  4 2023, 13:19:52)
 4 # [GCC 12.3.0]
 5 # Timestamp in code: 1708217267 (2024-02-17 19:47:47)
 6 # Source code size mod 2**32: 148 bytes
 7 # Method Name:       <module>
 8 # Filename:          five.py
 9 # Argument count:    0
10 # Position-only argument count: 0
11 # Keyword-only arguments: 0
12 # Number of locals:  0
13 # Stack size:        2
14 # Flags:             0x00000040 (NOFREE)
15 # First Line:        1
```

Disassembly using `pydisasm` from xdis

```
$ pydisasm /tmp/five_moved.pyc
```

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# pydisasm version 6.1.0
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# Stack size:        2
# Flags:             0x00000040 (NOFREE)
# First Line:        1
```

Disassembly using pydisasm from xdis

```
$ pydisasm /tmp/five_moved.pyc
```

```
19 #    2: 'five'
20 #    3: None
21 # Names:
22 #    0: __doc__
23 #    1: five
24 #    2: print
25   1:           0 LOAD_CONST          ("\nBlackHat Asia Example\n")
26                2 STORE_NAME          (__doc__)
27
28   6:           4 LOAD_CONST          (<code object five at 0x7f3f4c3d17c0, file "five.py",
29                6 LOAD_CONST          ("five")
30                8 MAKE_FUNCTION       (Neither defaults, keyword-only args, annotations, nor
31               10 STORE_NAME          (five)
32
33  12:          12 LOAD_NAME           (print)
```

Phases 1 and 2: Bytecode to Tokens

Bytecode Disassembly:

```
1: 0 LOAD_CONST       ('\nBlackHat Asia Example\n')
   2 STORE_NAME       (__doc__)

6: 4 LOAD_CONST       <code object five>
   6 LOAD_CONST       ('five')
   8 MAKE_FUNCTION    (No parameters)
  10 STORE_NAME       (five)
```

Parser Input Tokens:

```
1: 0  LOAD_STR          ('\nBlackHat Asia Example\n')
   2  STORE_NAME        (__doc__)

6: 4  LOAD_CODE          <code_object five>
   6  LOAD_STR          ('five')
   8  MAKE_FUNCTION_0   (No parameters)
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```

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   6  LOAD_STR          ('five')
   8  MAKE_FUNCTION_0   (No parameters)
  10  STORE_NAME        (five)
```

Phase 3: Parsing Tokens into a Parse Tree

```
"""
BlackHat Asia Example
"""
```

Constructing Parse Tree from Tokens:

```
LOAD_STR   '\nBlackHat Asia Example\n'
STORE_NAME __doc__
```

Phase 3: Parsing Tokens into a Parse Tree

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```
LOAD_STR
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```
expr  ::= LOAD_STR
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Parsing Tokens into a Parse Tree (Part 2)

Constructing Parse Tree from Tokens:

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```
STORE_NAME
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Parsing Tokens into a Parse Tree (Part 2)

Constructing Parse Tree from Tokens:

```
LOAD_STR
expr   ::= LOAD_STR
```

```
STORE_NAME
```

```
store    ::= STORE_NAME
```

Parsing Tokens into a Parse Tree (Part 2)

Constructing Parse Tree from Tokens:

```
LOAD_STR
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```

```
STORE_NAME
```

```
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Parsing Tokens into a Parse Tree (Part 3)

```
LOAD_STR
expr  ::= LOAD_STR
STORE_NAME
store   ::= STORE_NAME
```

Parsing Tokens into a Parse Tree (Part 3)

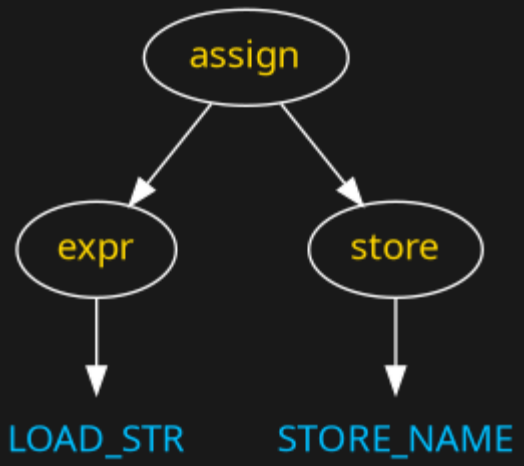
```
LOAD_STR
expr   ::= LOAD_STR
STORE_NAME
store    ::= STORE_NAME
```

```
assign   ::= expr store
```

Parsing Tokens into a Parse Tree (Part 3)

```
LOAD_STR
expr   ::= LOAD_STR
STORE_NAME
store    ::= STORE_NAME
```

```
assign   ::= expr store
```



Parsing Tokens into a Parse Tree (Part 4)

```
LOAD_STR
expr  ::= LOAD_STR
STORE_NAME
store   ::= STORE_NAME
assign  ::= expr store
```

Parsing Tokens into a Parse Tree (Part 4)

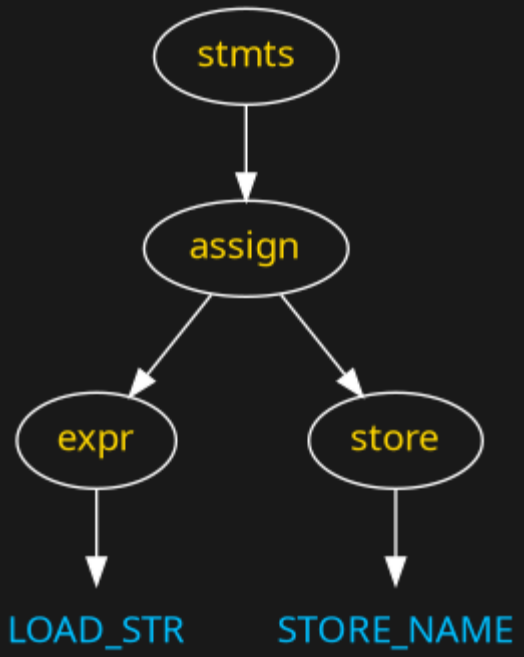
```
LOAD_STR
expr   ::= LOAD_STR
STORE_NAME
store    ::= STORE_NAME
assign   ::= expr store
```

```
stmts    ::= assign
```

Parsing Tokens into a Parse Tree (Part 4)

```
LOAD_STR
expr  ::= LOAD_STR
STORE_NAME
store   ::= STORE_NAME
assign  ::= expr store
```

```
stmts   ::= assign
```



Phases 3 - 5: Final Parse Tree to Source Text

Phase 3. Parse Tree in ASCII Format (First Line):

```
stmts
  0. assign
      0. expr
          L.  1   0  LOAD_STR    '\nBlackHat Asia Example\n'
      1. store
                 2  STORE_NAME   __doc__
```

Phases 3 - 5: Final Parse Tree to Source Text

Phase 3. Parse Tree in ASCII Format (First Line):

```
stmts
  0. assign
       0. expr
            L.  1   0  LOAD_STR    '\nBlackHat Asia Example\n'
       1. store
                   2  STORE_NAME   __doc__
```

Phase 4. Abstract Syntax Tree (First Line)

```
stmts
 0. docstring
        0  LOAD_STR    '\nBlackHat Asia Example\n'
        2  STORE_NAME  __doc__
```

Phases 3 - 5: Final Parse Tree to Source Text

Phase 3. Parse Tree in ASCII Format (First Line):

```
stmts
  0. assign
      0. expr
          L.  1   0  LOAD_STR    '\nBlackHat Asia Example\n'
      1. store
                 2  STORE_NAME   __doc__
```

Phase 4. Abstract Syntax Tree (First Line)

```
stmts
 0. docstring
       0  LOAD_STR    '\nBlackHat Asia Example\n'
       2  STORE_NAME  __doc__
```

Phase 5. Printing the Abstract Syntax Tree (First line)

```
"""
BlackHat Asia Example
"""
```


INTERMISSION

Bytecode Disassembly

```
 0 |64 00 5a 00 64 01 64 02 |
 8 |84 00 5a 01 65 02 65 00 |
16 |83 00 83 01 01 00 64 03 |
24 |53 00                   |
```

Bytecode Disassembly

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 0 |64 00 5a 00 64 01 64 02 |
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24 |53 00                   |
```

Disassembly using `pydisasm` from **`xdis`**:

Bytecode Disassembly

```
 0 |64 00 5a 00 64 01 64 02 |
 8 |84 00 5a 01 65 02 65 00 |
16 |83 00 83 01 01 00 64 03 |
24 |53 00                   |
```

Disassembly using `pydisasm` from **`xdis`**:

```
$ pydisasm -F extended-bytes -S __pycache__/five.cpython-38.pyc
```

Bytecode Disassembly

```
 0 |64 00 5a 00 64 01 64 02 |
 8 |84 00 5a 01 65 02 65 00 |
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```

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$ pydisasm -F extended-bytes -S __pycache__/five.cpython-38.pyc
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```
# ...
# Constants:
#    0: '\nBlackHat Asia Example\n'
#    1: <code object five at 0x7f64cb56c030, file "five.py", line 6>
#    2: 'five'
#    3: None
# Names:
#    0: __doc__
#    1: five
#    2: print
       # """\nBlackHat Asia Example\n"""
 1:      0 |64 00| LOAD_CONST        ("\nBlackHat Asia Example\n")
         2 |5a 00| STORE_NAME        (__doc__) ; __doc__ = '\nBlackHat Asia Example\n'

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 6:      4 |64 01| LOAD_CONST        (<code object five at 0x7f64cb56c030, file "five.py>)
         6 |64 02| LOAD_CONST        ("five")
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Bytecode Disassembly

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 8 |84 00 5a 01 65 02 65 00 |
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       # print(five())
```

Bytecode Disassembly

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 0 |64 00 5a 00 64 01 64 02 |
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Bytecode Disassembly

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 0 |64 00 5a 00 64 01 64 02 |
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24 |53 00                    |
```

```
$ pydisasm -F extended-bytes -S __pycache__/five.cpython-38.pyc
```

```
13           2 |5a 00| STORE_NAME        (__doc__) ; __doc__ = '\nBlackHat Asia Example\n'
14
15         # def five():
16  6:       4 |64 01| LOAD_CONST        (<code object five at 0x7f64cb56c030, file "five.py>)
17           6 |64 02| LOAD_CONST        ("five")
18           8 |84 00| MAKE_FUNCTION     (No arguments) ; TOS = def five(...): ...
19          10 |5a 01| STORE_NAME        (five) ; five = def five(...): ...
20
21         # print(five())
22 12:      12 |65 02| LOAD_NAME         (print)
23          14 |65 01| LOAD_NAME         (five)
24          16 |83 00| CALL_FUNCTION     (0 positional arguments) ; TOS = five()
25          18 |83 01| CALL_FUNCTION     (1 positional argument) ; TOS = print(five())
26          20 |01 00| POP_TOP
27          22 |64 03| LOAD_CONST        (None)
28          24 |53 00| RETURN_VALUE      return None
29
30
31 # Method Name:       five
32 # Filename:          five.py
33 # Argument count:    0
```

Chained Compare Bytecode

Python Expression: `"a" <= __file__ <= "b"`

```
1   1:     0 |64 00| LOAD_CONST           ("a")
2          2 |65 00| LOAD_NAME            (__file__)
3          4 |04 00| DUP_TOP
4          6 |03 00| ROT_THREE
5          8 |6b 01| COMPARE_OP           (<=)
6         10 |6f 12| JUMP_IF_FALSE_OR_POP (to 18)
7         12 |64 01| LOAD_CONST           ("b")
8         14 |6b 01| COMPARE_OP           (<=) ; TOS = (to 18) <= "b"
9         16 |6e 04| JUMP_FORWARD         (to 22)
10    >>  18 |02 00| ROT_TWO
11        20 |01 00| POP_TOP
12    >>  22 |01 00| POP_TOP
13        24 |64 02| LOAD_CONST           (None)
14        26 |53 00| RETURN_VALUE         return None
```

Chained Compare Bytecode

Python Expression: `"a" <= __file__ <= "b"`

```
1   1:     0 |64 00| LOAD_CONST          ("a")
2          2 |65 00| LOAD_NAME           (__file__)
3          4 |04 00| DUP_TOP
4          6 |03 00| ROT_THREE
5          8 |6b 01| COMPARE_OP          (<=)
6         10 |6f 12| JUMP_IF_FALSE_OR_POP (to 18)
7         12 |64 01| LOAD_CONST          ("b")
8         14 |6b 01| COMPARE_OP          (<=) ; TOS = (to 18) <= "b"
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```

Chained Compare Parse Tree (new code)

Python Expression: `"a" <= __file__ <= "b"`

```
BB_START 1 'Basic Block 1'
compare_chained
  0. expr
       ...
  1. compare_chained_middle
       ...
       4. jifop
            0.   10  JUMP_IF_FALSE_OR_POP    18  'to 18'
       1.        10  BB_END                 1   'Basic Block 1'
       5.        12  BB_START               2   'Basic Block 2'
       6. compare_chained_right
            ...
            2.   16  JUMP_FORWARD  22  'to 22'
            3.   16  BB_END         2   'Basic Block 2'
  2.             18  BB_START       3   'Basic Block 3'
  3.             18  SIBLING_BLOCK
  4.             18  ROT_TWO
  5.             20  POP_TOP
  6.             20  BB_END         3   'Basic Block 3'
  7.             20  BLOCK_END_JOIN 3   'Basic Block DominatorSet<{3}>'
```

Chained Compare Parse Tree (new code)

Python Expression: `"a" <= __file__ <= "b"`

```
BB_START 1 'Basic Block 1'
compare_chained
  0. expr
       ...
  1. compare_chained_middle
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       1.        10  BB_END                 1   'Basic Block 1'
       5.        12  BB_START               2   'Basic Block 2'
       6. compare_chained_right
            ...
            2.   16  JUMP_FORWARD  22  'to 22'
            3.   16  BB_END         2   'Basic Block 2'
  2.             18  BB_START       3   'Basic Block 3'
  3.             18  SIBLING_BLOCK
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```

Classifying Scopes and Important Control-Flow Points

```
1   i: int=6
2   zero_bits = 0
3   one_bits = 0
4   # loop dominator
5   while i > 0:
6      # if dominator
7      if i % 0:
8          # first sibling
9          one_bits += 1
10     else:
11         # second sibling
12         zero_bits += 1
13     # join point
14     i << 1
15  # loop-end join point
16  print(one_bits, zero_bits)
```

Classifying Scopes and Important Control-Flow Points

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```
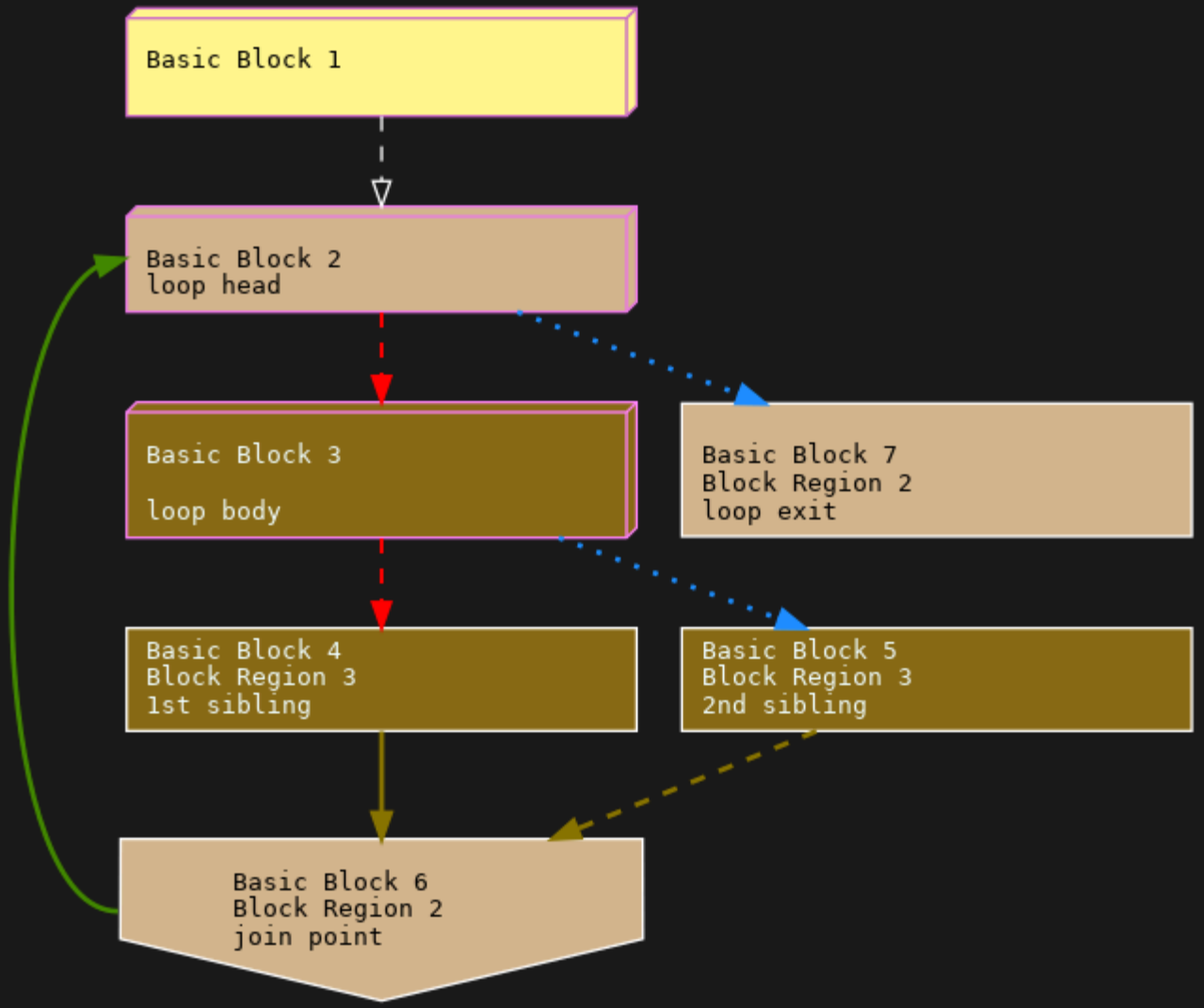

Control Flow Produced from `control_flow`

Dominator Regions and Dominators



General Remarks

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- Other Python decompilers

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- General-Purpose Decompilers

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- Other Python decompilers
- General-Purpose Decompilers
- How Control Flow Differs

General Remarks

- Other Python decompilers
- General-Purpose Decompilers
- How Control Flow Differs
- Choice of Intermediate Language

Wrapping Up

1. Understand, pinpoint, report, and even *fix* problems.
2. Understand how Python text code is related to its bytecode.
3. Extend this code for newer Python Bytecode.
4. Use these techniques in other High-level Bytecode Languages:

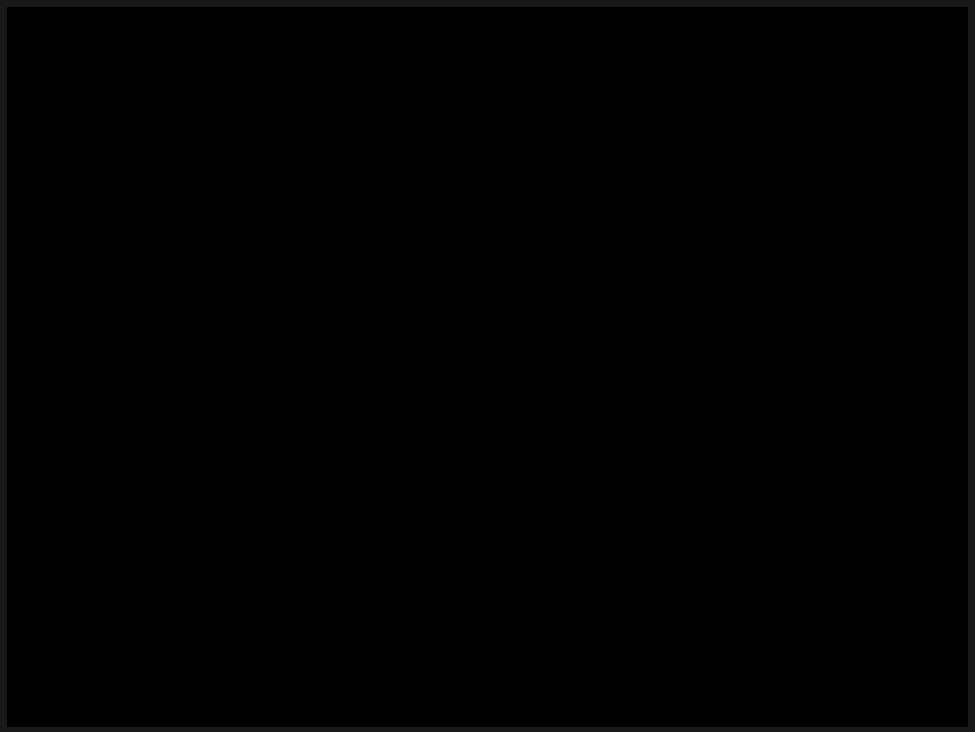
Thanks

- John Aycott and Hartmut Goebel
- BlackHat 2024 Asia Reviewers and Organizers
- Phil Young and Speaker-Coaching Program
- Lidia, Christina, Huisi (AV)
- Stuart Frankel
- You

Additional Information

- Python Decompilers: https://pypi.org/project/uncompyle6, and https://pypi.org/project/decompyle3/
- Cross-Version Python Disassembler: https://pypi.org/project/xdis
- Python Control Flow: https://github.com/rocky/python-control-flow
- Older Decompiler Paper: https://rocky.github.io/Deparsing-Paper.pdf
- PyCon Columbia 2018 talk slides: https://rocky.github.io/pycon2018-light.co
- PyCon Columbia 2018 talk video: https://www.youtube.com/watch?v=bRQr1OroXUM&feature=youtu.be
- Slide Text: https://rocky.github.io/blackhat-asia-2024-additional/all-notes-print
- Additional Slides: https://rocky.github.io/blackhat-asia/2024-additional

We’re late again...



Bye now...