Prototyping Go’s Select with stackless.py for Stackless Python

Andrew Francis
af.stackless@gmail.com
http://andrewfr.wordpress.com

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Erratum July 27th, 2010

- Spelling and coding mistakes corrected
- New slides in earlier version reinserted
  - Pages 15, 48, 53,57,58
  - Mentioned in talk
  - Makes slides easier to follow
- Smiths Intro ☺
- Please read blog at http://andrewfr.wordpress.com for additional information and comments

Panic on the streets of London
Panic on the streets of Birmingham
I wonder to myself
Could life ever be sane again ?

From Panic by The Smiths

Purpose

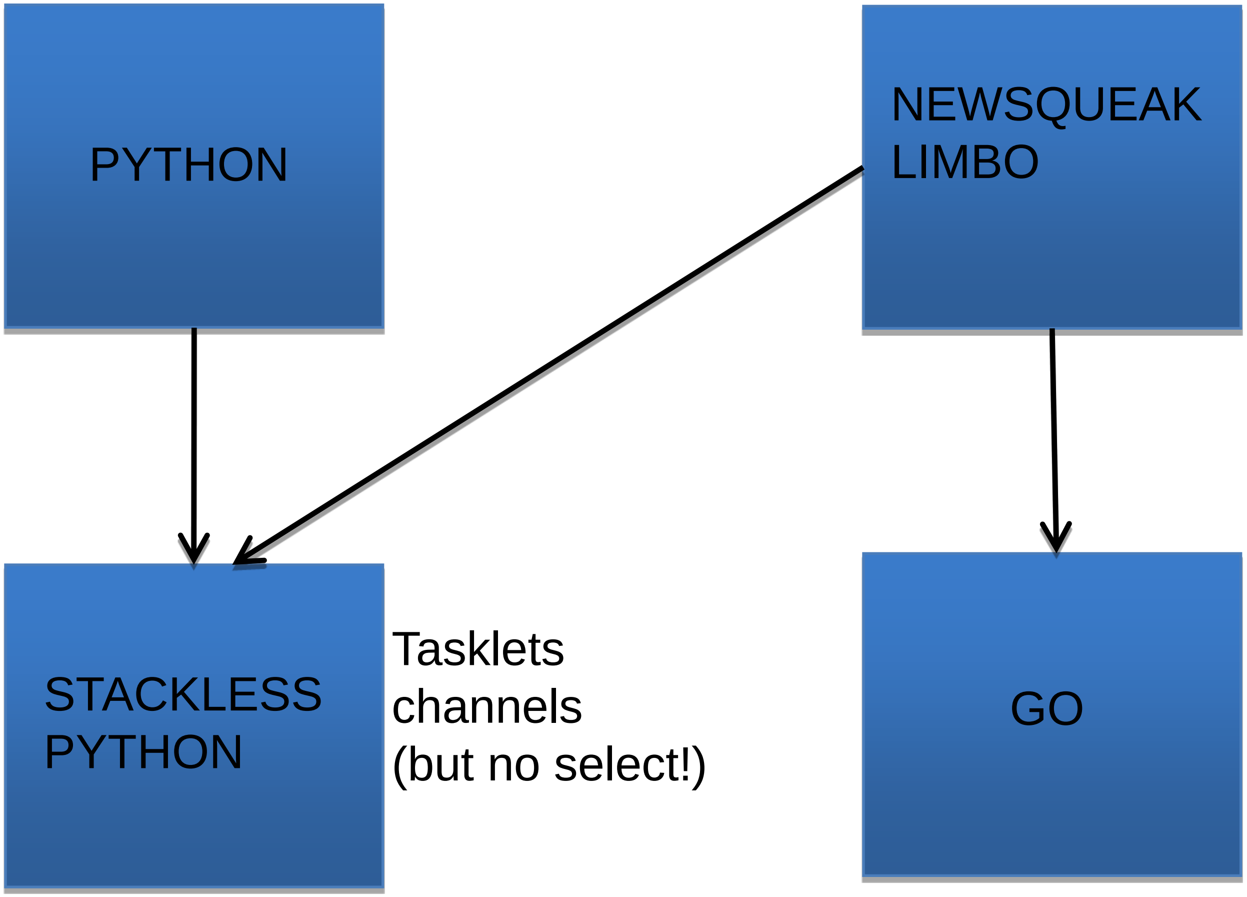
- To show how PyPy's stackless.py module can be used to prototype new concurrency features for Stackless Python
  - Stackless Python is a superset of Python renowned for microthreads too cheap to meter.
  - Stackless Python also great for writing new concurrency constructs!

Why Prototype with stackless.py?

- Occasionally there are concurrency constructs that are difficult to correctly implement solely with Stackless Python’s classes
  - need finer control over scheduling
  - Need to supplant underlying C data structures

- Prototyping with Stackless Python’s C code base a costly way to experiment

Why Go's Select : A Family Tree



PYTHON

NEWSQUEAK
LIMBO

"Processes" (coroutines),
channels,
alt (select)

STACKLESS
PYTHON

Tasklets
channels
(but no select!)

GO

Goroutines
channels
select

By The Way

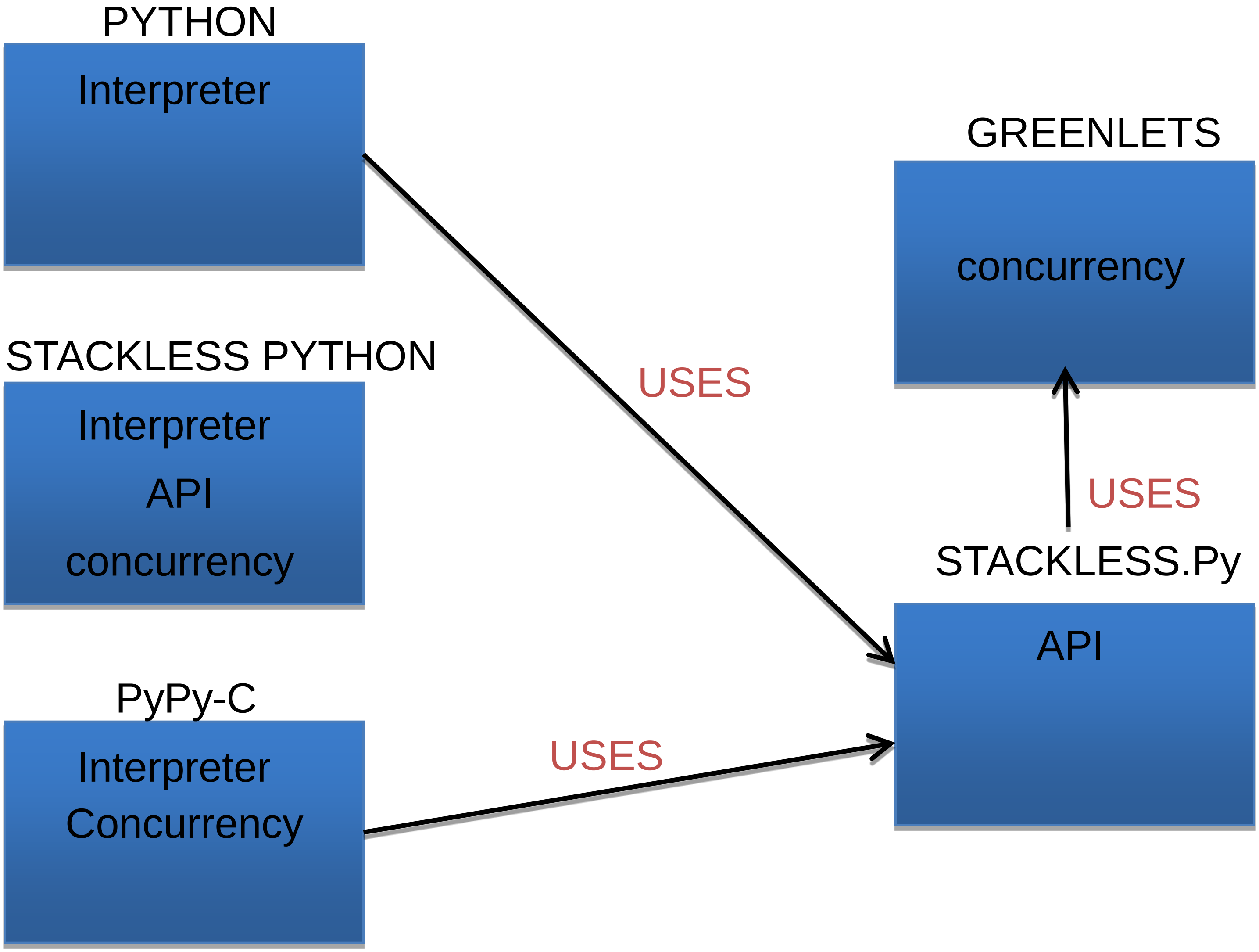
Select allows a coroutine to wait on multiple channels for an action to occur without resorting to polling

(conceptually similar but not the same as UNIX select)

Questions Explored through Prototyping

- What is a suitable interface for a Stackless Python select?
- What would internally change?
- How would pre-existing Stackless Python applications break?

The Cast of Characters



PYTHON

Interpreter

STACKLESS PYTHON

Interpreter

API

concurrency

PyPy-C

Interpreter

Concurrency

GREENLETS

concurrency

STACKLESS.Py

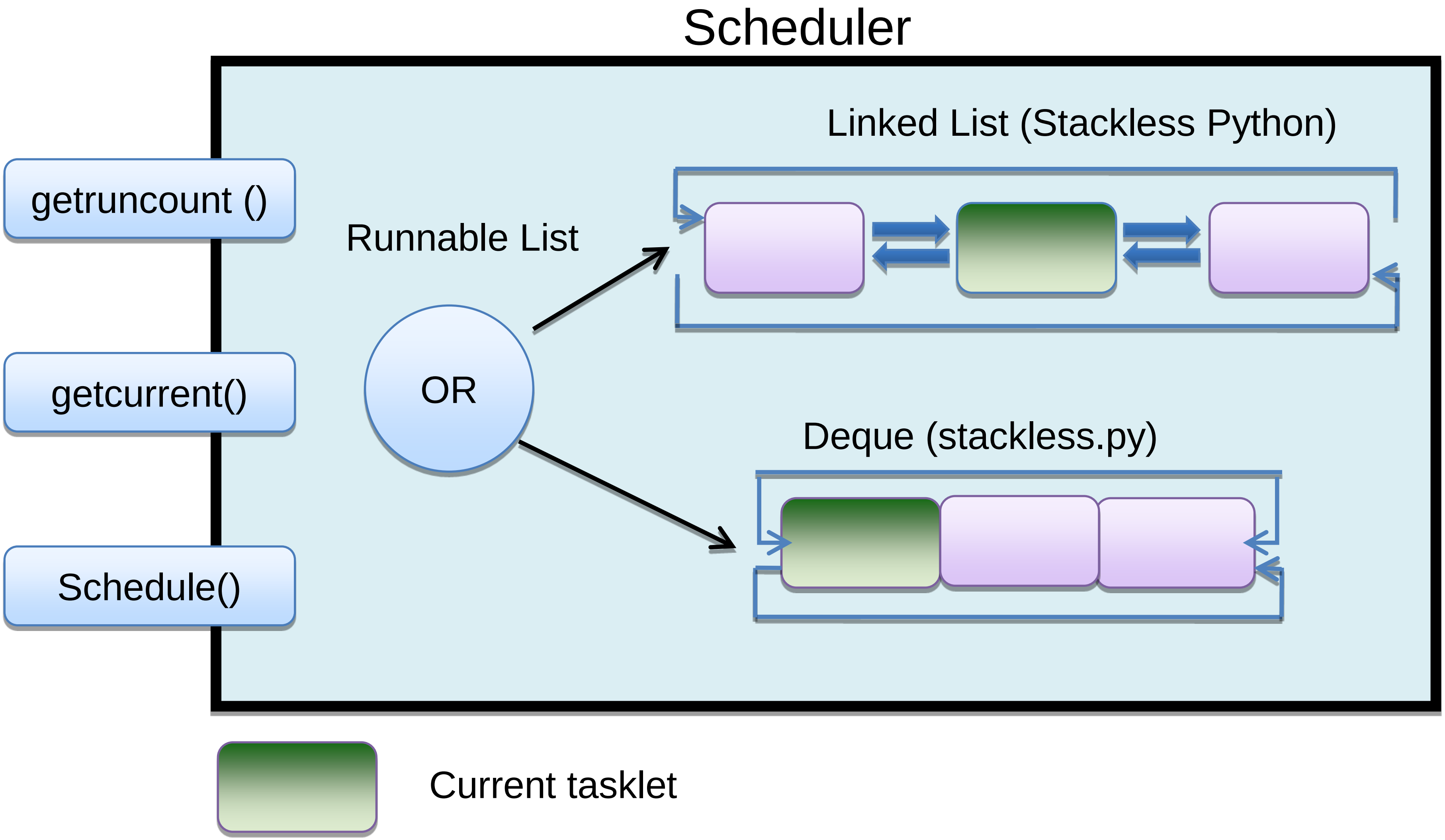
API

USES

USES

USES

Implementation Details



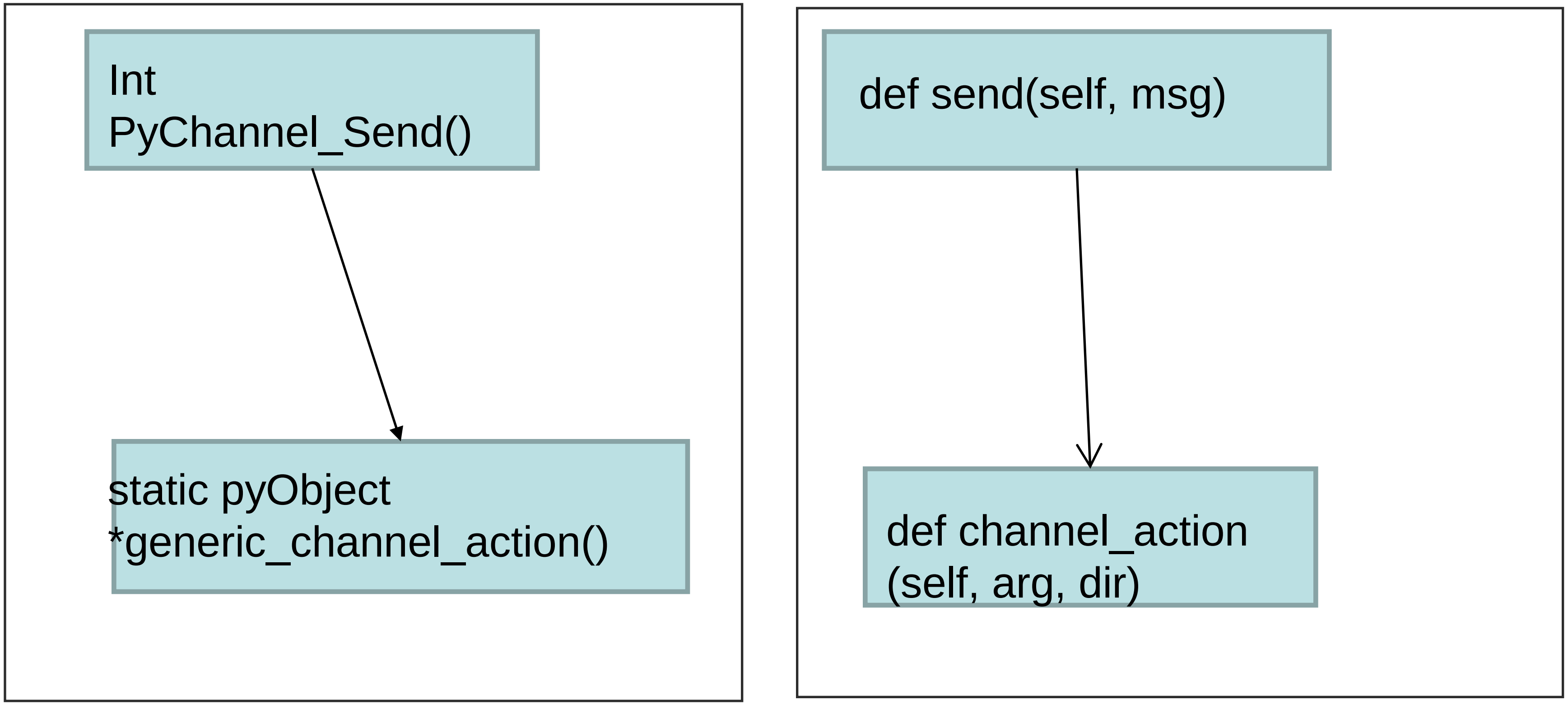
The Approach

- Read Rob Pike’s paper “The Implementation of Newsqueak”
  - includes great description of the channel based message passing algorithm
  - An important theme is the opacity of the underlying system’s state to the application
  - First prototype was based solely on Pike’s description

Approach Continued: Quick survey of source code

chanelobject.c

stackless.py



Int
PyChannel_Send()

static pyObject
*generic_channel_action()

def send(self, msg)

def channel_action
(self, arg, dir)

Mimics Stackless Python’s logical structure. Other variants of stackless.py don’t

Approach Continued
Ask Questions

- Asked questions in Go Lang Nuts and Stackless mailing lists
  - GoLang Nuts: Rob Pike, Russ Cox, Ian Taylor
    - Read libthread/channel.c
    - Thanks guys for humouring me!
  - Stackless: Christian Tismer and Richard Tew
    - Select cannot be done in pure Stackless without additional tasklets

Prototyping

- Late April to June Sunday sessions
  - partner Kevin Bulušek (Thanks!)
- Two prototypes done by end of April
  - implementation of an eventHandler
    - Got familiar with issues and stackless.py
  - Stackless Python mock-up based on Plan 9’s libthread (Kevin)
    - An API for select
    - data structures

stackless.py and Stackless Python versions discussed in the remainder of this paper based on Plan9 mockup

An Overview of Stackless Python and Go

Introduction

```
andrew@parker:~/lab/stacklessSelect/comparisons$ python
Python 2.6.5 Stackless 3.1b3 060516 (python-2.65:82030M, Jun 26
2010, 15:49:57)
[GCC 4.3.3] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>> import stackless
[32376 refs]
>>> dir(stackless)
['__doc__', '__name__', '__reduce__', '__reduce_ex__', '_gc_track',
'_gc_untrack', '_get_all_objects', '_get_refinfo', '_pickle_moduledict',
'_wrap', 'bomb', 'cframe', 'channel', 'cstack', 'enable_softswitch',
'get_thread_info', 'getcurrent', 'getmain', 'getruncount', 'run',
'schedule', 'schedule_remove', 'select', 'set_channel_callback',
'set_schedule_callback', 'slpmodule', 'stackless', 'tasklet',
'test_cframe', 'test_cframe_nr', 'test_cstate', 'test_outside']
', 'set_ignore_nesting', 'setup', 'tempval', 'thread_id']
```

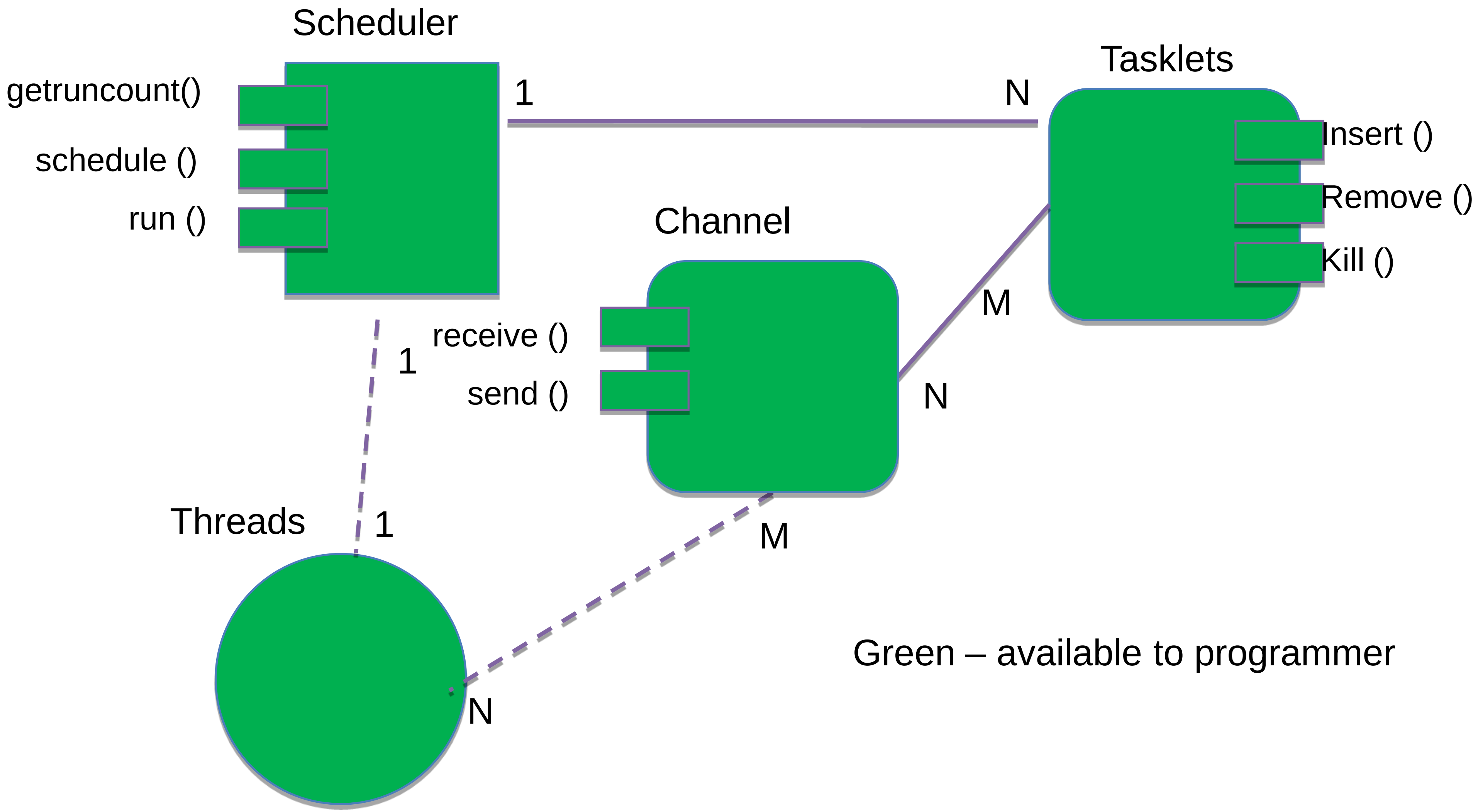
Stackless Python Elements

- Tasklets
  - User space light weight threads
  - Executes actual work
- Scheduler
  - Performances context switching between tasklets
  - Uses a round-robin scheduling
  - Two modes: pre-emptive and cooperative

Channels

- Used for communications and synchronization
- Bi-directional
- Can support iteration
- An object including channels and exceptions can be passed
- Can be subclassed

Stackless Python's World



Green – available to programmer

Simple Stackless Programme

```
import stackless

def reader(channel):
    print "entering reader"
    print channel.receive()
    print "exiting reader"


def writer(channel):
    print "entering writer"
    channel.send("hello world")
    print "exiting writer"

if __name__ == "__main__":
   ch = stackless.channel()
   stackless.tasklet(reader)(ch)
   stackless.tasklet(writer)(ch)
   stackless.run()
```

Output

```
entering reader
entering writer
hello world
exiting reader
exiting writer
```

A Bad Channel Equivalent

```
import stackless

tempVal = None

class namedTasklet(stackless.tasklet):
     name = None

     def __repr__(self):
          return self.name

def reader():
    global tempVal
    print "entering reader"
    stackless.schedule()
    print tempVal
    print "exiting reader"

def printQueue():
    h = stackless.getcurrent()
    p = h
    while True:
        print "->", p
        p = p.next
        if p == h:
           break
```

```
def writer():
    global tempVal
    print "entering writer"
    tempVal = "hello world"
    t.remove()
    stackless.schedule()
    print "exiting writer"

def publisher(t):
    print "entering publisher"
    printQueue()
    t.insert()
    print
    printQueue()
    stackless.schedule()
    print "exiting publisher"

if __name__ == "__main__":
    t = namedTasklet(reader)()
    t.name = "reader"
    x = namedTasklet(writer)()
    x.name = "writer"
    x = namedTasklet(publisher)(t)
    x.name = "publisher"
    stackless.run()
```

Output

```
entering reader
entering writer
entering publisher
-> publisher
-> writer

-> publisher
-> writer
-> reader
exiting writer
hello world
exiting reader
exiting publisher
```

tasklet.insert() places reader at the end of the runnable list

Why is Bad Important?

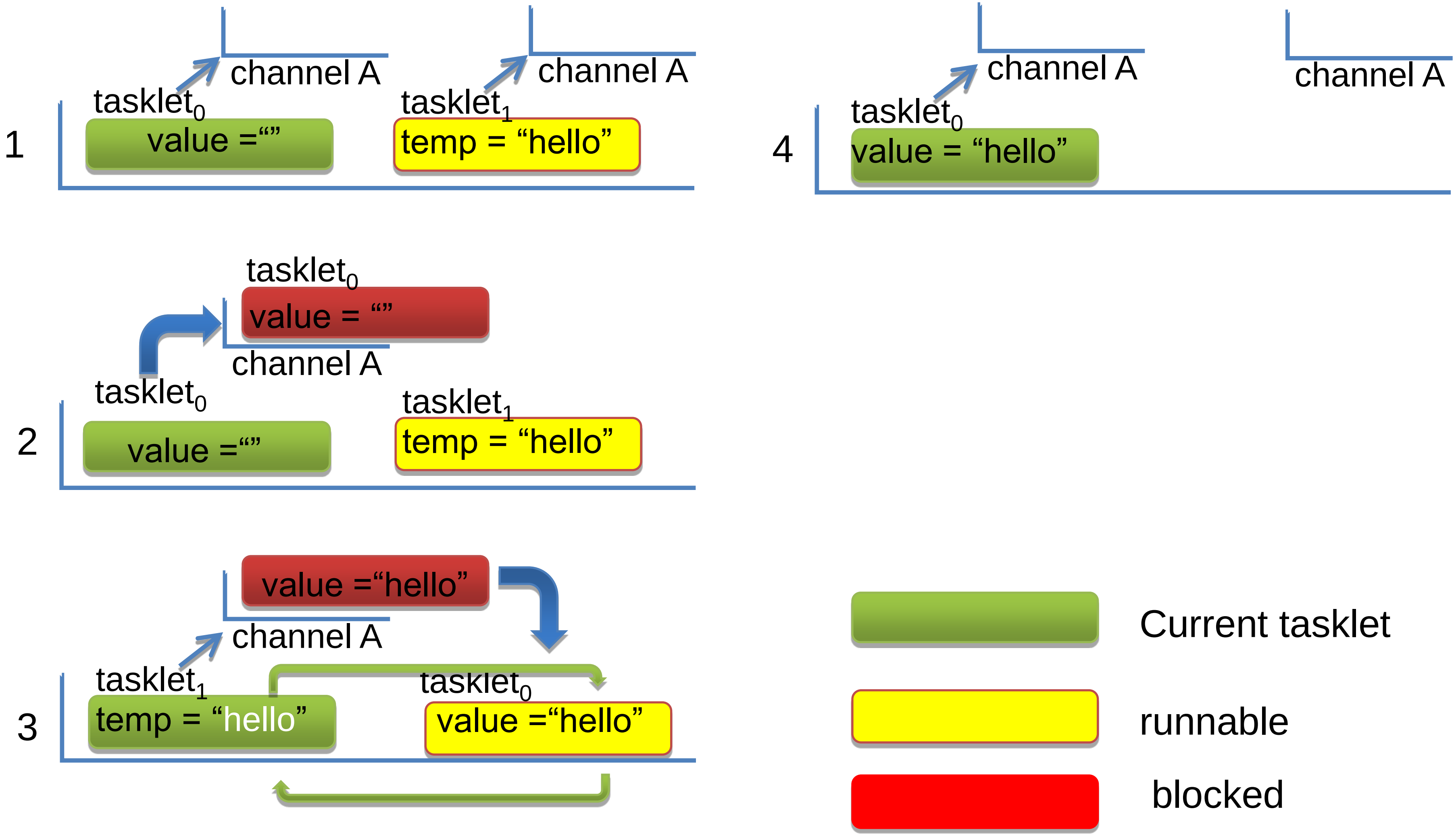
- Demonstrates that channels can be constructed from lower level methods available to the programmer, i.e.,
  - schedule()
  - schedule_remove()
- Application programmer has considerable access to the scheduler
- Almost all the building blocks are there to build select using the Stackless API!

but not enough to implement select ….

Channels: Rendezvous Semantics

- For a successful communication to occur there must be a sending tasklet and a receiving tasklet
  - active tasklet is the source
  - inactive tasklet the target
- If there is not a target, the active tasklet will block until another tasklet performs a complimentary operation

How Channels Work



Channel Implementation Details:

```
>>> dir(stackless.channel)
['__class__', '__delattr__', '__doc__', '__format__', '__getattribute__',
'__hash__', '__init__', '__iter__', '__module__', '__new__', '__reduce__',
'__reduce_ex__', '__repr__', '__setattr__', '__setstate__', '__sizeof__',
'__slots__', '__str__', '__subclasshook__', 'balance', 'close', 'closed',
'closing', 'next', 'open', 'preference', 'queue', 'receive', 'schedule_all',
'send', 'send_exception', 'send_sequence]
```

-Channel.balance determines whether a tasklet will block

-A balance of zero causes the tasklet to block

- blocked tasklets are placed on a FIFO queue

-send() increments balance by 1

-receive() decrements balance by 1

A limitation of the rendezvous semantics model

```
def eventHandler(channels):
    while True:
        for ch in channels:
            message = ch.receive()
            stackless.tasklet(doSomething)(message)
```

Ch[0] ready after T + 10
Ch[1] ready after T + 15
Ch[2] ready after T + 1
Ch[3] ready after T + 2

Clearly this is a throughput problem….

Enter Go

- Very different from Python
  - Statically typed
  - Compiled
  - limited OO features
- Similar concurrency constructs
  - Implemented as language features
  - Support for multiple CPUs

Simple Go Programme

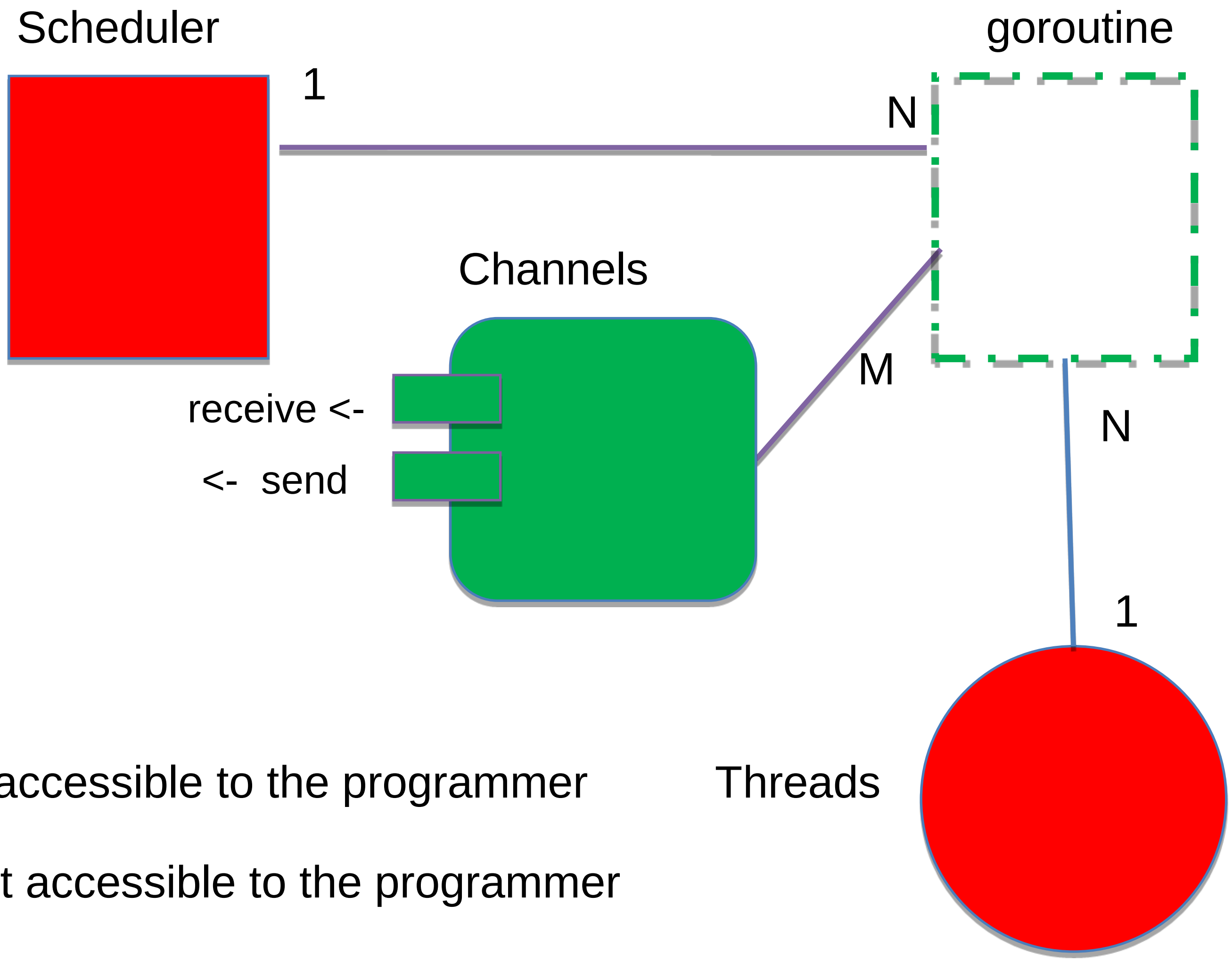
```
package main

import fmt "fmt“

func reader(in chan int) {
    fmt.Printf("entering reader\n");
    x := <- in;
    fmt.Printf("->%d \n", x);
    fmt.Printf("exiting reader\n");
    in <- 1
}


func writer(out chan int) {
    fmt.Printf("entering writer\n");
    out <- 1;
    fmt.Printf("exiting writer\n");
}
```

```
func main() {
    var ch = make(chan int);
    fmt.Printf("I got here \n");
    go reader(ch);
    go writer(ch);
    fmt.Printf("Main Ending \n");
    <-ch;
}
```

Go Constructs

Go	Stackless Python
variable <- channel	variable = channel.receive()
channel <- variable	channel.send(variable)
data, ok = ch <- variable	if channel.balance != 0

Go’s World



Green – accessible to the programmer

Red – not accessible to the programmer

So?

- ‘Bad’ example could not be implemented in Go
  - goroutines not manipulatable by programmer
  - Scheduler almost totally opaque to the programmer
- Under the hood
  - Support for multiple CPUs requires extensive locking
- Is fine grained control over the scheduler in such an environment desirable?

The Select Statement

```
select {
case a := <- ch[0]:
     go doSomething(a);
case b := <- ch[1]
     go doSomething(b);
case c := <- ch[2]
     go doSomething(c);
case d := <- ch[3]:
     go doSomething(d);
}
```

Could We Implement Select with Only Stackless Python?

- Yes
  - Use an additional tasklet per case
    - And an extra join channel
  - Hard to mimic behaviour
    - Problem dealing with tasklets that unblock after the select has finished
    - The 20% that requires 80% of the effort?
  - Bad performance?

Fragment of a Pseudo Solution

```
def select(cases):
    selector = stackless.channel()

    def case(ch,operation, value):
        if operation == RECEIVE:
           value = ch.receive()
        else:
           ch.send(value)

        selector.send((ch, operation, value))

    for ch, op, value in cases:
        stackless.tasklet(case)(ch, op, value)

    # block until a case is ready
    # the hard part is dealing with the remaining channels
    retChannel, retOperation, retVal = selector.receive()
```

stackless.py

Section four

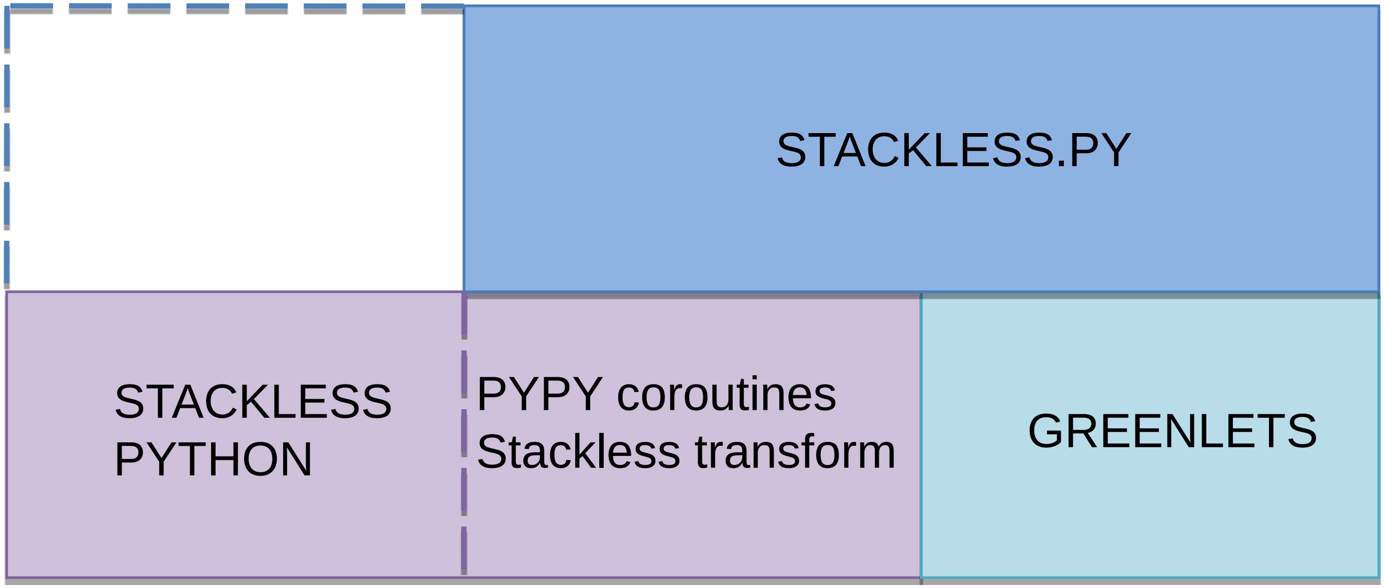
Description

- A Python based implementation of the Stackless Python module
  - scheduler, channels, tasklets
  - Single file, roughly 650 lines

- Part of the PyPy Framework
  - Currently PyPy implements Python 2.5
  - Although Stackless is implemented, it is not integrated with the JIT.

```
andrew@parker:~$ pypy-c
Python 2.5.2 (75825, Jul 05 2010, 02:48:27)
[PyPy 1.3.0] on linux2
Type "help", "copyright", "credits" or "license" for more information.
And now for something completely different: ``it's not a hack, it's a
workaround''
>>>> import stackless
>>>> dir(stackless)
['DEBUG',  'TaskletExit', '__all__', '__builtins__', '__doc__', '__file__', '__name__',
'__nrand_next', '_channel_callback', ,'_global_task_id', '_init', '_last_task',
'_main_coroutine', '_main_tasklet', '_run_calls', '_schedule_callback',
'_scheduler_append', '_scheduler_contains', '_scheduler_remove',
'_scheduler_switch', '_squeue', '_stackless_primitive_registry', 'bomb',
'channel', 'coroutine', 'debug', 'deque', 'dprint', 'getcurrent', 'getmain',
'getruncount', 'greenlet', 'nrand', 'operator', 'register_stackless_primitive',
'rewrite_stackless_primitive', 'run', 'schedule', 'schedule_remove',
'set_channel_callback', 'set_schedule_callback', 'sys', 'tasklet',
'traceback']
>>>>
```

stackless.py’s Abstraction Layer



Example of Abstraction Layer in code

```
try:
    from _stackless import coroutine, greenlet
except ImportError: # we are running from CPython
    from greenlet import greenlet
    try:
        from functools import partial
    except ImportError: # we are not running python 2.5
```

Usage

- Stackless.py resides in pypy/lib or lib_pypy
- PyPy interpreter on top of Standard Python
  - Too slow
  - Defeats purpose of rapid prototyping
- pypy-c
  - Like Stackless Python requires a separate binary
  - Avoid lengthy build by getting precompiled version

A Trick of the Trade

- Use the Greenlets package with standard Python
  - Low level microthreading package
  - Many Python packages use greenlets
    - Eventlets
    - gEvent
  - stackless.py already included!
- This is the approach the PyPy team used to develop stackless.py module

Limitations

- Does not support threads
- Does not support pre-emptive mode
- Does not implement all of the attributes in the various Stackless Python classes

The Select Algorithm

Section Five

Imitation is the sincerest form of flattery

or

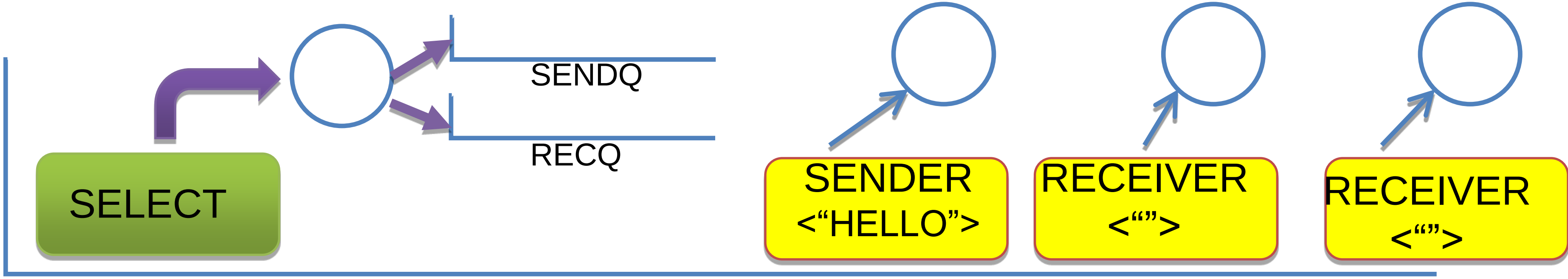
Good artists copy, great artists steal

(Steve Jobs quoting Picasso)

```
def select(operations):
    choice = None
    source = getcurrent()
    numberReady = 0

    for operation in operations:
        if operation.ready():
           numberReady += 1
           if nrand(numberReady) == 0:
               choice = operation

    if choice:
        choice.action()
    else:
        for operation in operations:
            operation.add()

        schedule_remove()
        schedule()

        choice = self._operation
        source._operation = None

    return choice.result()
```

Select Under the Hood

Structure of a Channel



SELECT

SENDQ

RECQ

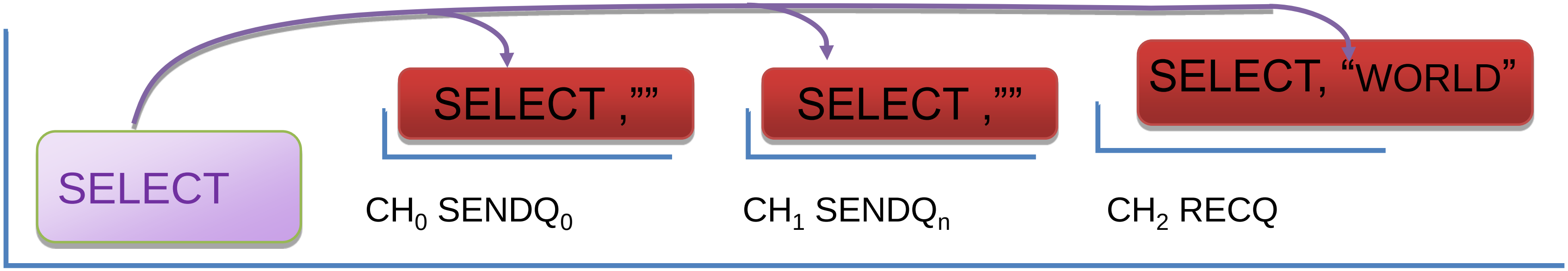
SENDER
<“HELLO”>

RECEIVER
<“”>

RECEIVER
<“”>

Runnable Queue

BLOCKING



SELECT

SELECT ,””

SELECT ,””

SELECT, “WORLD”

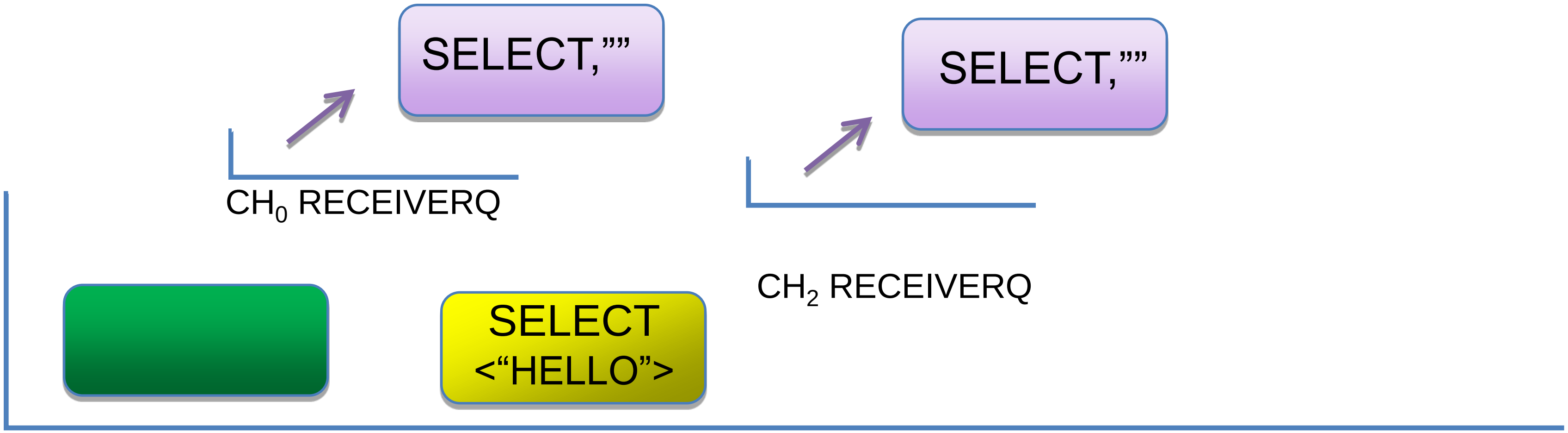
CH_0 $SENDQ_0$

CH_1 $SENDQ_n$

CH_2 RECQ

Select Under the Hood

Tear Down



- the source coroutine
- Transfers data to target (with select)
- Takes select coroutine off the participating channel queues
- Places target on the runnable list

def _channel_action()

```
def _channel_action(self, operation):

    if _channel_callback is not None:
        _channel_callback(self, getcurrent(), operation)

        target = self.queue

        operation.copyOperation(target)
        target.tasklet._operation = target

        #clear operation from remaining channels
        target.removeall()

        target.tasklet.blocked = 0
```

Source channel responsible for moving data and tearing down channels

An Elegant Hack

In Plan9, a channel.send/receive is equivalent to a select with a single case (read operation)!

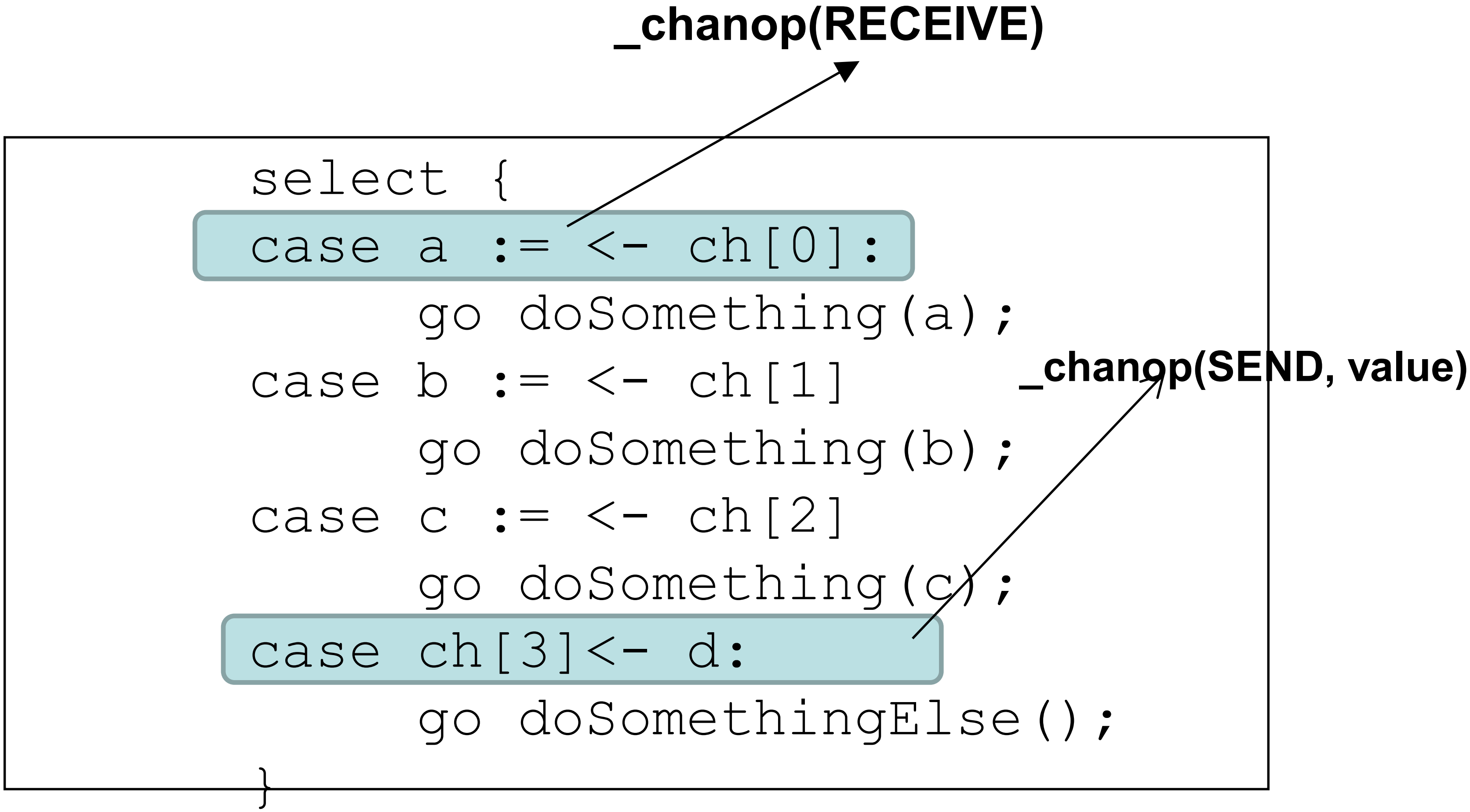
Implementing select with stackless.py

Section Five

New Stackless Methods

- stackless.select(list of chanops)
  - returns (channel, operation, value)
- channel.sendCase()
  - returns _chanop
- channel.receiveCase()
  - returns _chanop

New Class: _chanop



_chanop(RECEIVE)

```
select {
case a := <- ch[0]:
        go doSomething(a);
case b := <- ch[1]
        go doSomething(b);
case c := <- ch[2]
        go doSomething(c);
case ch[3]<- d:
        go doSomethingElse();
}
```

_chanop(SEND, value)

Why _chanop?

- In stackless Python, a channel can be blocked only on one channel
  - tempval associated with channel.send()
  - *source.tempval, target.tempval* = *target.tempval, source.tempval* always works

Why _chanop Continued

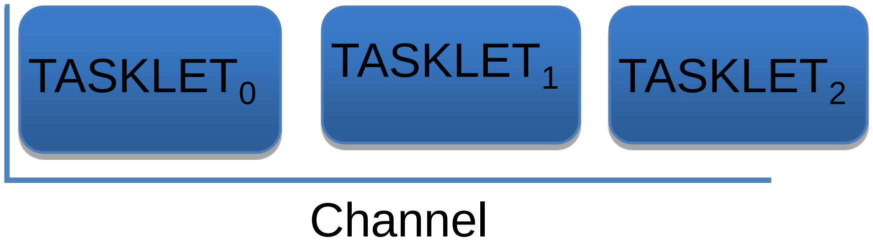
- With select a tasklet can be blocked on many channels
- The special case is when selector is the target
  - Which tempval does the source target associate with its channel?
- Two options
  - Do a look up for tempval based on channel
  - Place channel, operation, and data on the channel queue

Example

```
def selector(a,b,c):
   while flag:
      ch, operation, value = stackless.select([a.sendCase("A"),
b.receiveCase(), c.sendCase("C")])

      if ch == a:
         print "sender A completed"
      elif ch == b:
         print "received ", value, "from receiver B"
      elif ch == c:
         print "sender C completed“
         flag = False
      else:
         print "should not get here"
```

Changes to Channels

BEFORE



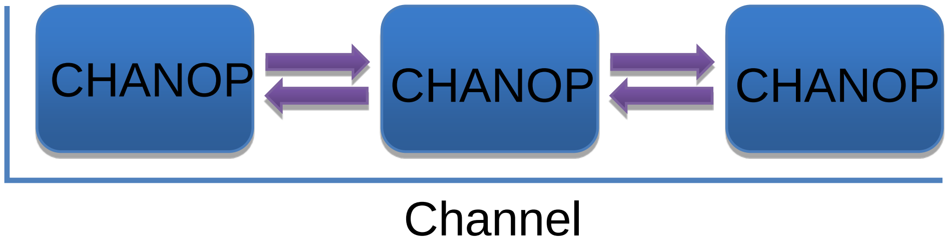
TASKLET_0

TASKLET_1

TASKLET_2

Channel

AFTER



CHANOP

CHANOP

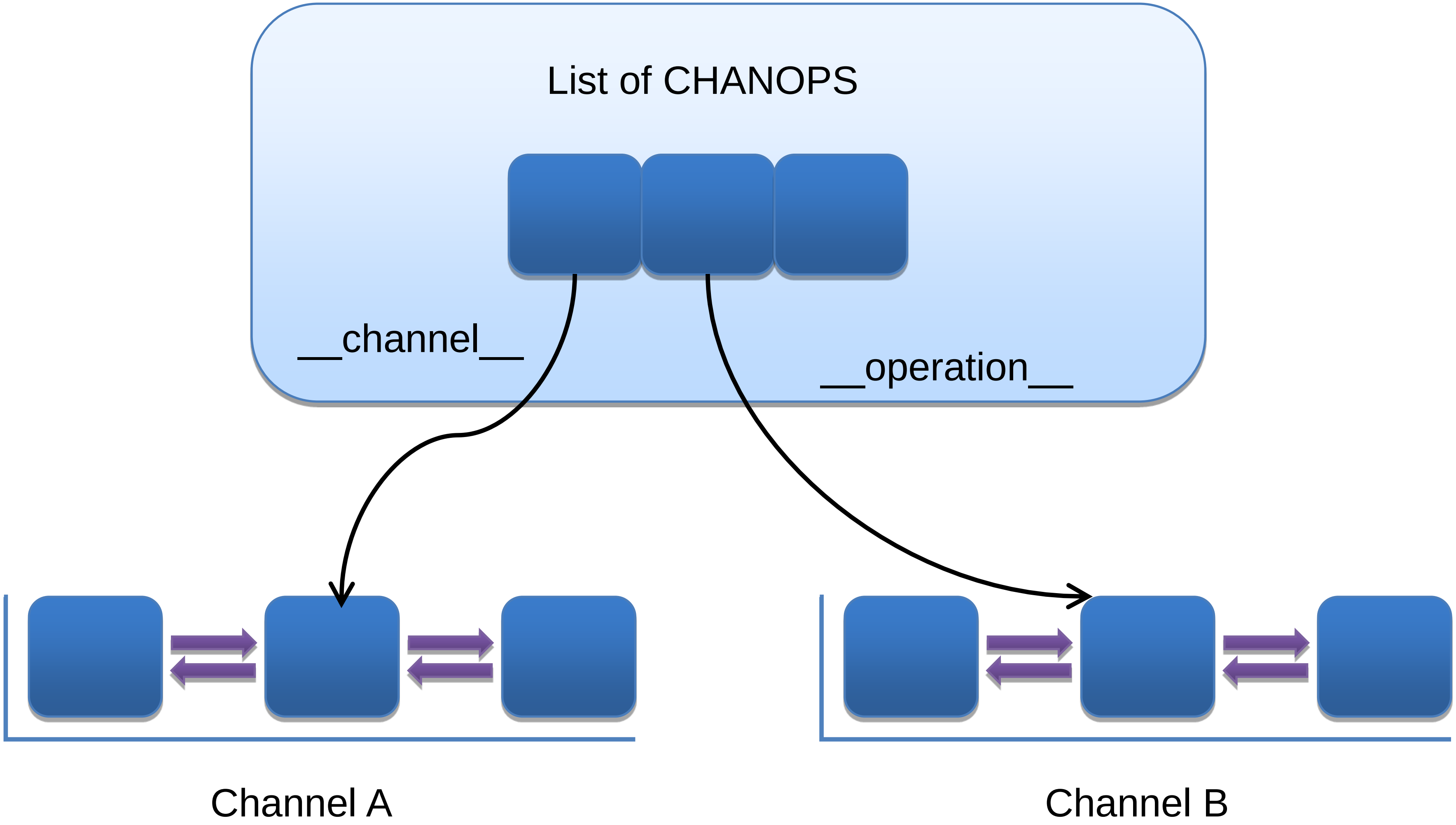
CHANOP

Channel

New Channel Methods

- channel.addOperation(chanop)
  - need way to add operations to channels without blocking

Changes to Tasklets



Short Cuts

- For now, separate send and receive queues are not implemented.
- channel.balance remains
  - it is so handy…
- Limitation
  - A receive chanop and send chanop cannot be on the same channel queue

What Breaks?

- Only applications that depends on internal state
  - A channel queue now consists of chanops not tasklets
  - What does __channel__ now mean?
  - channel.balance could disappear.

Moving to Stackless Python

Section Five

The Stackless Python C Version

- Programmer now responsible for
  - Setting up house keeping structures (especially for C Extensions)
  - Memory allocation
  - Reference counting
  - Manipulating complex data structures
- Stackless Python C code much more verbose
  - ~1000 lines versus ~150

Example: Channel_action

```
PyAltObject *
slp_alt_action(PyAltObject *self)
{
        PyThreadState *ts = PyThreadState_GET();
        PyTaskletObject *t = ts->st.current;
        PyAltObject *target;

        assert(PyAlt_Check(self));
        assert(self->tasklet == t);

        target = slp_channel_remove(self->channel);
        if (target == NULL)
                return NULL;
```

Compare to Python equivalent in previous section

Channel_action Continued

```
        assert(PyAlt_Check(target));
        assert(target->tasklet != t);

        Py_INCREF(target);

        alt_copy(self, target);
        alt_remove_all(target);

        target->tasklet->flags.blocked = 0;

        return target;
}
```

Summary of C Code

- Most of the changes are isolated in:
  - channel’s generic_channel_action
  - The alt object
- Stackless Python C code is just a C equivalent of the stackless.py code
- Esoteric issues concerning stack frames and locks are avoided
  - The GIL is our friend

Conclusions

Section Six

Lessons Learnt

- Select is an extreme example of customization
- Select relative easy to implement but requires substantial changes
- Clean room descriptions good
- Concentrate on proper API
- Initially copy to learn.
- Get working prototypes up and running quickly

Status

- Not quite prime time
  - Slight signature differences between C and stackless.py
  - C version fails a few unit tests
    - Mostly pertaining to pickling
  - Problems with complex select tests
    - Both C and stackless.py
  - Performance problem with stackless.py
    - A bug with channel preferences?

However this was meant to be a prototype not production code!

Whither C Stackless Python?

- Psyco JIT/Stackless Python integration will make
  - Stackless binaries a thing of the past
  - Minimize the need for writing C-extensions
- PyPy-C
  - with JIT, faster than CPython
  - What will happen when stackless support is integrated with the JIT?
  - Let’s make this happen!

Future Directions

- Experiment with supporting select as a language feature
- Optimize select
  - Can we avoid costly teardowns?
- Prototype other concurrency features
  - Join patterns a la Polyphonic #C and Jocaml
  - Is this a gateway to Complex Event Processing?

Have Prototype Will Travel!

References

- “The Implementation of Newsqueak” by Rob Pike
- http://www.stackless.com
- http://codespeak.net/pypy/dist/pypy/doc/stackless.html
- The GoLang-Nuts mailing list
- http://swtch.com/usr/local/plan9/src/libthread/channel.c
- “Stuff What I Posted”, Richard Tew’s Blog

Acknowledgements

- Special thanks to
  - Kevin Bulušek !!!! (especially for writing the C implementation)
  - Annette Hollman (for helping me with the slides)
  - The McGill Continuing Education Student Building staff (MACES)
  - And ….

For allowing me to do a dry run of this talk!

Questions?

Thank You