Design Patterns…

…Beyond the Gang of Four

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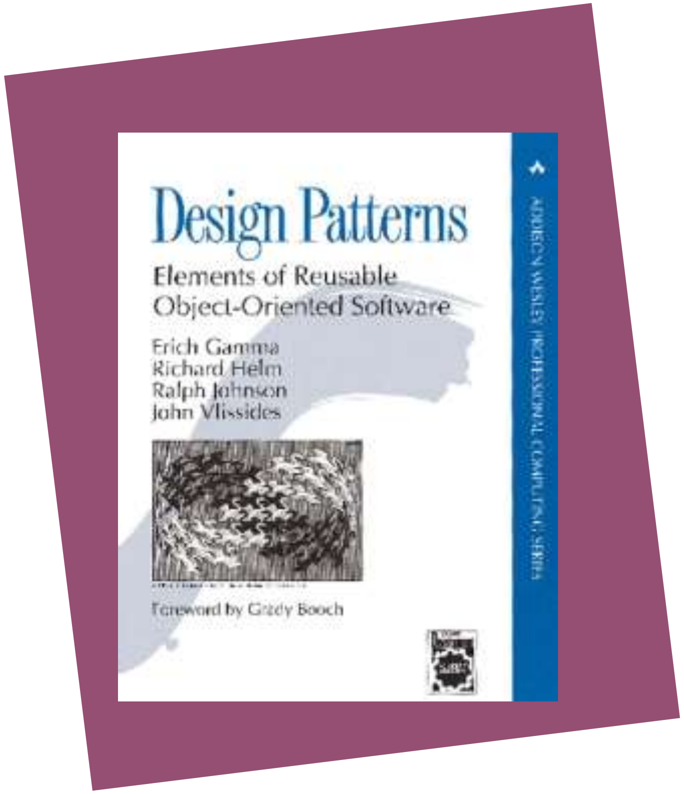
What are Patterns?

- Reusable design ideas
  - Good software design approaches
  - “Discovered” rather than “invented”
  - Solution to a problem in a context
- How many patterns?
  - General software design (GoF)
  - Communications software
  - Reliability
  - Analysis
  - Agile development process


Design Patterns
Elements of Reusable Object-Oriented Software
Erich Gamma
Richard Helm
Ralph Johnson
John Vlissides
Foreword by Grady Booch
ADDISON-WESLEY PROFESSIONAL COMPUTING SERIES

- Why do we use them? Profit from the experience of others…

“Gang of Four” = popular 1994 book by Erich Gamma, Richard Helm, Ralph Johnson, John Vlissides

How do patterns work?

Step 1: You have a design problem…

- "I have three applications need to display changing data"

Step 2: Look for a pattern that matches your problem and context

- "I think the **Observer** pattern might help"

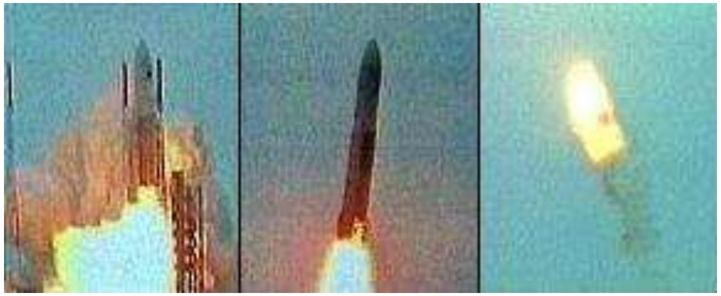
Step 3: Create the design based on the pattern example

- "I am going to define two classes: Subject and Observer"
  - Subject holds the data, Observer updates the display
- "I am going to define attach() and notify() functions in the new classes"
  - Subject class has a linked list of pointers to Observers
  - Observer objects can call xSubject.attach(myself) to register for notification
  - Whenever a Subject changes state, it calls xObserver.notify() on each registered Observer

Step 4: Include information about the pattern in the design documentation

What could go wrong?

- Patterns are not a simple cookie cutter…
  - You need to consider the context
  - Each pattern has "Consequences" (for example, Observer pattern could cause a slow and inefficient cascade of updates)



When you use your pattern, it might trigger the need for one or more related patterns:

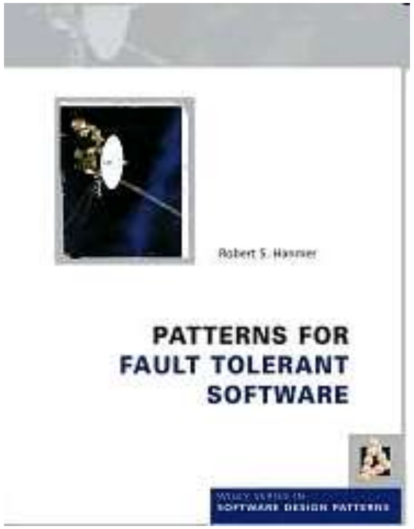
- A "pattern language" is a group of connected patterns
- We will talk about a few pattern languages for specialized contexts

It's easy to go "pattern happy"

- (making the application extra complicated just so we can show off how many patterns we can use)

Reliability patterns

- How to make a complex system more reliable
  - Replication
  - Check data inputs
  - Monitor critical processes
  - Overload control policies
  - Recover/restart failed elements
- Several good sources of reliability patterns
  - *Patterns for Fault-Tolerant Software* by Robert Hanmer
  - *Robust Communications Software* by Greg Utas


Robert S. Hanmer
PATTERNS FOR FAULT TOLERANT SOFTWARE
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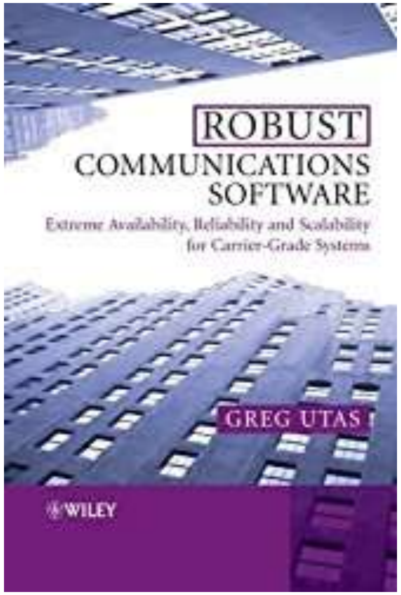
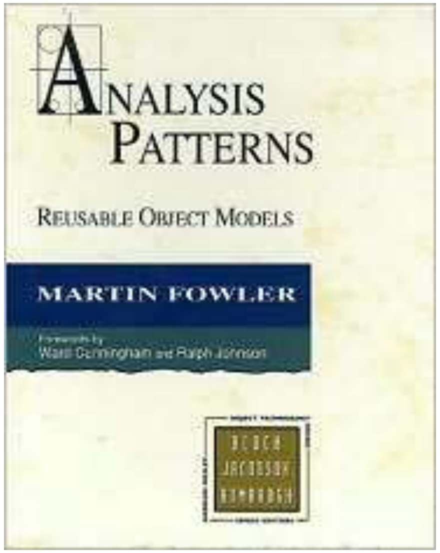

ROBUST COMMUNICATIONS SOFTWARE
Extreme Availability, Reliability and Scalability for Carrier-Grade Systems
GREG UTAS
WILEY

Reliability patterns

- A complex system needs to use a group of patterns
  - Error detection, error recovery, error mitigation
- A few “error detection” patterns
  - **Routine Audit** – the system is designed to run periodic checks on its internal data
    - If errors are found, the system might use a “correcting audit” to repair the data
  - **Watchdog** – there is special hardware or software that watches a key element of the system
    - Monitor one key task to make sure it is alive and working correctly – trigger a restart if fails
  - **System Monitor** – more elaborate than a Watchdog, monitor the behavior of multiple system elements
    - Trigger repair or recovery when there is a problem

Quantity pattern

- Analysis patterns are a set of patterns that are used in doing the initial problem analysis:
  - They help answer the question “what objects should I define in my system?”
- The **Quantity** pattern is from the book *Analysis Patterns* by Martin Fowler
  - Recording measurements and manipulating results might be error-prone
  - Each value really should be recorded with its units:



- A Money object will have both a number and an identifier to say which currency:
  [19.95, “US Dollars”]; [700, “Euros”]; [100, “Yuan”]

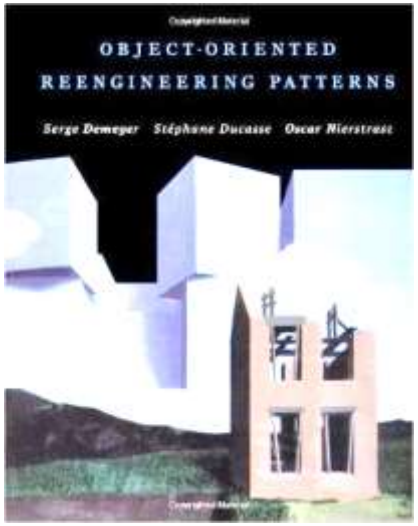
- Length and weight also need units:
  [100, “miles”]; [15.5, “kg”]

Justification for the Quantity pattern

- A frequent problem – someone tries to perform an invalid operation on two different types of quantities:
  - adding apples to oranges, people to money, dates to time intervals
  - conversion mistakes: adding dollars to euros, inches to feet
  - performing an average of a mixed bag of objects (this should never be legal)
- Using explicit units in the design makes it easier for someone else to understand the software later
  - what does this number mean??

Reengineering patterns

- Some patterns go beyond the initial design
  - The book Object-oriented Reengineering Patterns has some valuable “redesign” ideas
  - Redesign = changing an existing software system to meet new needs
  - And… the original developers might not be available
- The **Facade** pattern is really useful (and it is a GoF pattern)
  - Build wrappers around existing modules
  - Analyze the data to decide what to wrap
  - Benefit: Reduces coupling
  - Benefit: Helps support evolution – some modules can be updated without affecting others



Reengineering patterns

- An extremely useful reengineering pattern: **Write Tests to Enable Evolution**
  - Analyze key system scenarios – create some automated tests that exercise parts of the scenarios
  - Use automated test frameworks, to make it easy to run the tests frequently
- The tests can support refactoring
  - When you make minor changes to algorithms or data structures, it is easier to test if anything was broken
  - Tests have an impact on overall system quality
- Focus on parts of the system that are changing rapidly
  - Add new tests in each product release

Automated testing – costs and benefits

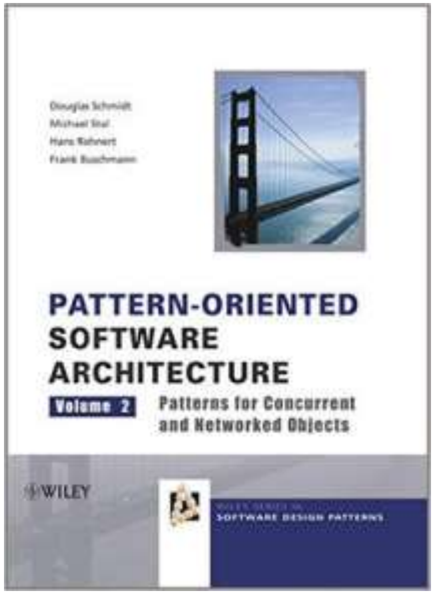
- It can take a lot of effort to add new tests to software
  - Don’t do it all at once – focus on key scenarios
- Tests are sometimes difficult to maintain
  - Avoid writing automated tests of the user interface details – it is better to test the internal functionality before the UI interactions
- Benefits:
  - Increased confidence in the system as a whole
  - Less risk when modules are turned over to new staff
  - It is easier to make small changes with confidence
  - Tests are a good form of “documentation” – much more precise than text descriptions

Communications patterns

- Most interesting software applications are not “isolated”
  - Applications designed to interact with other applications
  - Or use a database on a central server
  - Or relay events to a central controller
- Applications that are split
  - between a small device (cell phone, smart appliance)
  - and a larger network-based system
- Concurrency – take advantage of multi-core systems
  - Use “threads” for independent operations
  - But some synchronization is still needed

Communications patterns

- Patterns for processing “events” in a complex system
  - **Reactor**, **Proactor** – two different approaches for reacting to events from multiple processes
- Patterns for communication – distributed, concurrent, multi-threaded
  - **Monitor**, **Active Object** – two different approaches for setting up communicating services
- A good place to start is the book *Pattern-Oriented Software Architecture, Vol. 2*



Active Object pattern

- Problem: how to build small collaborating modules
- Context: distributed or multi-threaded application; modular structure is needed to support frequent changes to the application
- Solution: make each module an Active Object
  - Each Active Object has a "message queue" – where it receives service requests
  - The implementation of the Active Object is an infinite loop: processing requests from other parts of the system

It is easy to do this in multiple programming languages:

- In Java or Python, build on the Thread class
- In C++, use C++11 threads, Boost library, or the ACE framework
- Commercial and open source frameworks (QP, Theron, Orbit, libagents)

Active Object example

- Word frequency counter in Python (based on an example by Crista Lopes)

```
$ python ./wfcounter.py inputfile.txt
mostly  -  2
live  -  2
in  -  2
africa  -  1
tigers  -  1
india  -  1
lions  -  1
wild  -  1
white  -  1
```

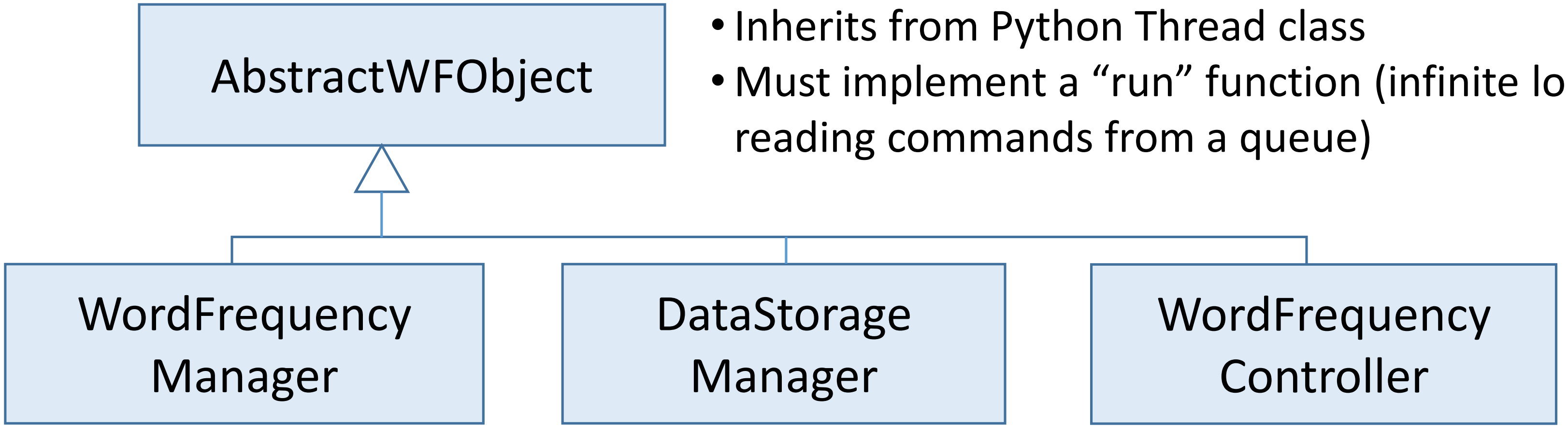
inputfile.txt

```
White tigers live mostly in India
Wild lions live mostly in Africa
```

We could write a “monolithic program” to do the counting,
But let’s try doing it with a multi-threaded application!

Active Object example

- Create abstract base class for Active Objects in our application – inherits from Python Thread class:



- Inherits from Python Thread class
- Must implement a “run” function (infinite loop reading commands from a queue)

```
class ActiveWFObject(Thread):
    def __init__(self):
        Thread.__init__(self)
        self.name = str(type(self))
        self.queue = Queue()
        self._stop = False
        self.start()
```

```
def run(self):
    while not self._stop:
        message = self.queue.get()
        self._dispatch(message)
        if message[0] == 'die':
            self._stop = True
```

Active Object – Word Frequency Manager

- WordFrequencyManager – keeps a Python dictionary with “words” and “counts”
- Other objects will send it some words:

```
class WordFrequencyManager(ActiveWFObject):
  """ Keeps the word frequency data """
  _word_freqs = {}

  def _dispatch(self, message):
    if message[0] == ‘word’:
      self._increment_count(message[1:])

  def _increment_count(self, message):
    word = message[0]
    if word in self._word_freqs:
      self._word_freqs[word] += 1
    else:
      self._word_freqs[word] = 1
```

A typical message might contain:
[‘word’, ‘tigers’]

Active Object – Data Storage Manager

- DataStorageManager – read in words from a file, send one word at a time to the WordFrequencyManager
- First step: read in the entire file, eliminate extra white space and punctuation, convert to lower case

```
class DataStorageManager(ActiveWFObject):
   _data = ‘’

   def _dispatch(self, message):
      if message[0] == ‘init’:
         self._init(message[1:])

   def _init(self, message):
      path_to_file = message[0]
      self._word_freqs_manager = message[1]
      with open(path_to_file) as f:
         self._data = f.read()
      pattern = re.compile(‘[\W_]+’)
      self._data = pattern.sub(‘ ‘, self._data).lower()
```

If the file was:

White tigers
live
mostly   in   India.

the new self._data string will be:

white tigers live mostly in india

Active Object – Data Storage Manager

- DataStorageManager – process all of the words in the file

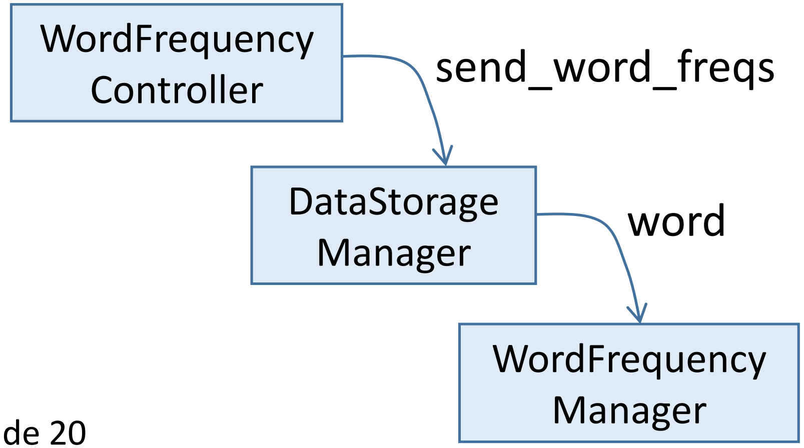
```
class DataStorageManager(ActiveWFObject):
   _data = ‘’

   def _dispatch(self, message):
      if message[0] == ‘init’:
         self._init(message[1:])
      elif message[0] == ‘send_word_freqs’:
         self._process_words(message[1:])

   def _process_words(self, message):
      data_str = ‘’.join(self._data)
      words = data_str.split()
      for w in words:
         send(self._word_freqs_manager, [‘word’, w])
      send(self._word_freqs_manager, [‘top25’, message[1]])
```

The send function will add a request to the queue for the WordFrequencyManager Active Object…

Active Object – Word Frequency Controller

- WordFrequencyController – starts the counting, reports results

```
class WordFrequencyController(ActiveWFObject):

   def _dispatch(self, message):
      if message[0] == 'run':
         self._run(message[1:])

   def _run(self, message):
      self._storage_manager = message[0]
      send(self._storage_manager, ['send_word_freqs', self])
```



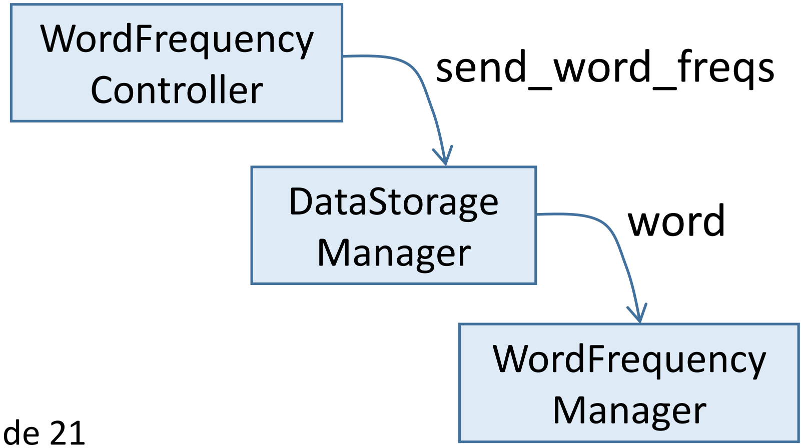
Not done yet… still need to report the frequency counts…

Active Object – Word Frequency Controller

- WordFrequencyController – starts the counting, reports results

```
class DataStorageManager(ActiveWFObject):
  def _process_words(self, message):
    data_str = ''.join(self._data)
    words = data_str.split()
    for w in words:
      send(self._word_freqs_manager, ['word', w])
    send(self._word_freqs_manager, ['top25', message[1]])
```

Tell the WordFrequencyManager to sort and report



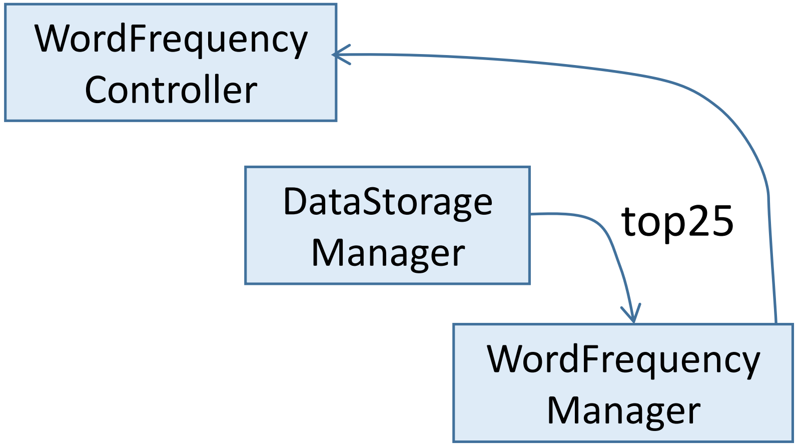
WordFrequency Controller

send_word_freqs

DataStorage Manager

word

WordFrequency Manager



WordFrequency Controller

DataStorage Manager

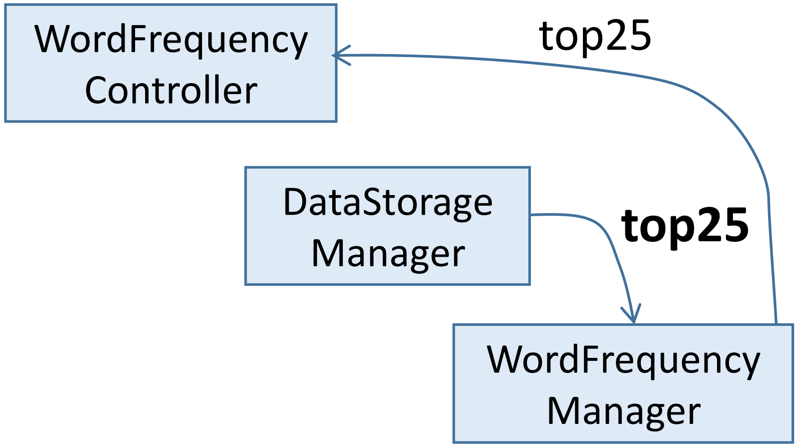
top25

WordFrequency Manager

Active Object – report results

- Add a new “top25” message to WordFrequencyManager – create a sorted list of word counts, send to the controller

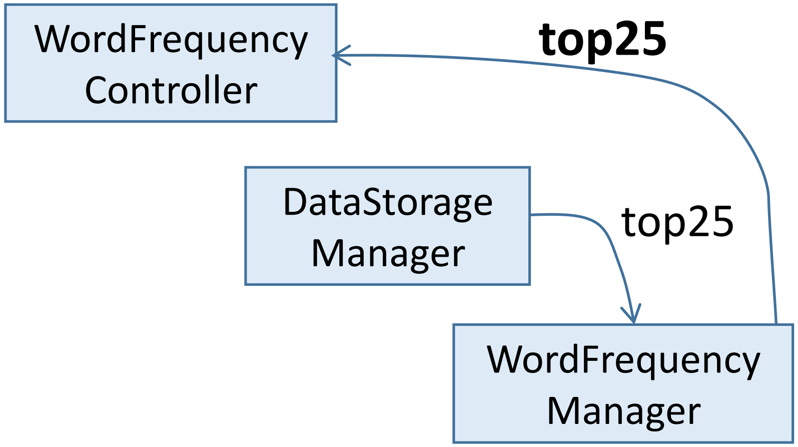
```
class WordFrequencyManager(ActiveWFObject):
    """ Keeps the word frequency data """
    _word_freqs = {}

    def _dispatch(self, message):
        if message[0] == ‘word’:
            self._increment_count(message[1:])
        elif message[0] == ‘top25’:
            self._top25(message[1:])

    def _top25(self, message):
        recipient = message[0]
        freqs_sorted = sorted(self._word_freqs.iteritems(),
                key=operator.itemgetter(1), reverse=True)
        send(recipient, [‘top25’, freqs_sorted])
```



Active Object – report results

- Add a new “top25” message to WordFrequencyController – display the word counts

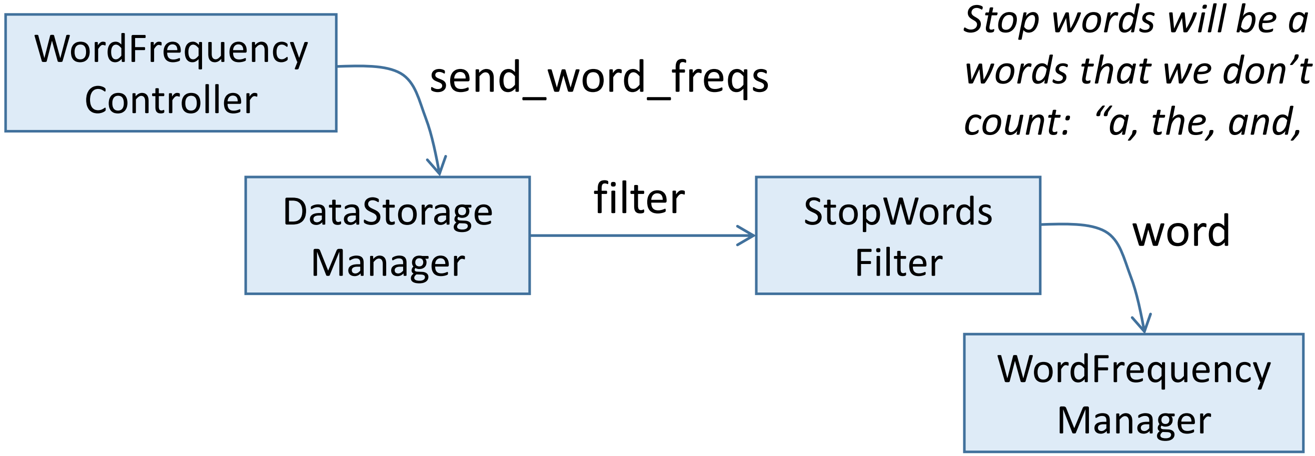
```
class WordFrequencyController(ActiveWFObject):
   def _dispatch(self, message):
      if message[0] == 'run':
         self._run(message[1:])
      elif message[0] == 'top25':
         self._display(message[1:])

   def _display(self, message):
      word_freqs = message[0]
      for (w, f) in word_freqs[0:25]:
         print w, ' - ', f
      send(self._storage_manager, ['die'])
      self._stop = True
```



Report the data that was sent by the WordFrequencyManager…

Is this a good pattern?

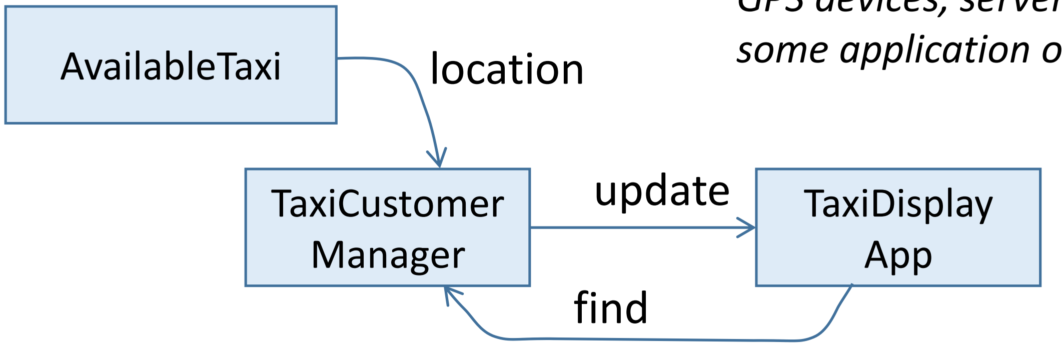
- Is this a good way to implement this program?
  - Maybe – it is very modular, and we can add new modules to augment the functionality
  - For example: to filter out "common words", we can add a new Active Object called StopWordsFilter – between the DataStoreManager and the WordFrequencyManager



Stop words will be a list of simple words that we don't want to count: "a, the, and, but, if, …"

Is this a good pattern?

- The pattern is even more useful for simple control and communications applications:
  - Active Objects to monitor the state of real-world objects
  - Active Objects to “wrap” some of the services available in a large client-server application



A distributed application that requires information from multiple GPS devices, server objects, and some application objects

Useful links related to Active Object

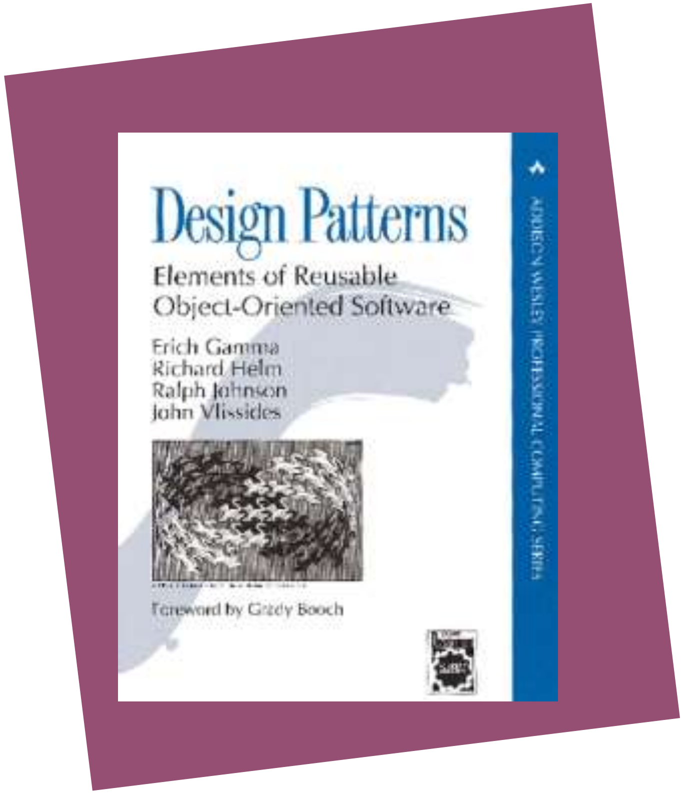
- The Word Frequency Counter example is based on a section of the book *Exercises in Programming Styles* by Cristina Lopes
    - github.com/crista/exercises-in-programming-style/tree/master/28-actors
- Useful notes on implementing Active Objects:
    - pragprog.com/magazines/2013-05/java-active-objects
    - www.codeproject.com/articles/991641/revisiting-the-active-object-pattern-with-cplusplu
    - www.drdobbs.com/parallel/prefer-using-active-objects-instead-of-n/225700095
- There are other approaches to building multi-threaded systems:
    - Active Object is a “thread per object” approach
    - In some server-based applications, “thread per request” can be better – especially for services that have a long execution time
    - More complex: several concurrent operations might be changing the state of a single object – the design of the request code might need to use *semaphores* to control access to critical sections

Books and articles

- Martin Fowler, *Analysis Patterns* (Addison-Wesley, 1996)
- Serge Demeyer, Stephane Ducasse, and Oscar Nierstrasz, *Object Oriented Reengineering Patterns* (Morgan-Kaufmann, 2003)
    - http://www.iam.unibe.ch/~scg/OORP
- Greg Utas, *Robust Communications Software* (Wiley, 2005)
- Robert S. Hanmer, *Patterns for Fault Tolerant Softwar*e (Wiley, 2007)
- *Pattern Oriented Software Architecture, volume 2* by Doug Schmidt, Michael Stal, Hans Rohnert, and Frank Buschmann (Wiley, 2000)

What have we learned?

- Extend your range!
  - The GoF book is great, but…
  - More patterns for other contexts
  - We are writing more concurrent and distributed software
  - Reliability is increasingly important
  - And building on legacy software is always valuable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- Add to your design vocabulary…

This talk:
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