

# Pipeline Architecture

## *Software Architecture*

Brae Webb

March 6, 2023

*So far...*

Layered architectures reduce the impact of changing a layer

*Question*

Why does the layer order matter?

*Question*

Why does the layer order matter?

*Answer*

Each layer implements a different interface.

*So...*

If every layer implements the same interface?

*Extreme layered architecture*

# Pipeline Architectures<sup>1</sup>

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<sup>1</sup>sorta

*Definition 1.* Pipeline Architecture

Components connected in such a way that the output of one component is the input of another.

*Question*

Can you think of a *pipeline architecture*?



*Question*

Can you think of a *pipeline architecture*?

*Answer*

How about *bash*?

```
1 >> cat assignment.py | grep "hack" | wc -l \  
2   | tee code-quality.txt
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Notice:

- Each program performs a small well-defined task.

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1 >> cat assignment.py | grep "hack" | wc -l \  
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```

Notice:

- Each program performs a small well-defined task.
- Each program implements the same interface (i.e. raw text).

```
1 >> cat assignment.py | grep "hack" | wc -l \  
2   | tee code-quality.txt
```

cat assignment.py

grep "hack"

wc -l

tee code-quality.txt





Filters

Modular software components



Filters

Modular software components

Pipes

The flow of data between filters



# Types of filters

Producers

Source of data.

## Types of filters

### Producers

Source of data.

### Transformers

Transform data.

# Types of filters

## Producers

Source of data.

## Transformers

Transform data.

## Testers

Filter data.

# Types of filters

Producers

Source of data.

Testers

Filter data.

Transformers

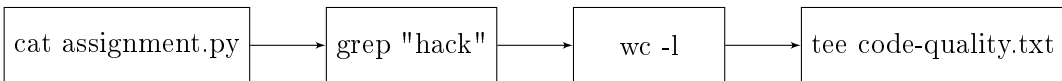
Transform data.

Consumers

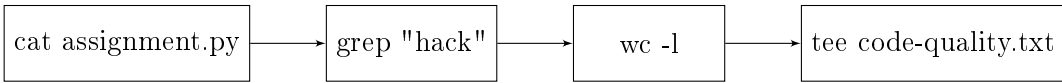
Target for results.

*Exercise*

Label the bash pipeline.



Producer



Producer

cat assignment.py



Tester

grep "hack"

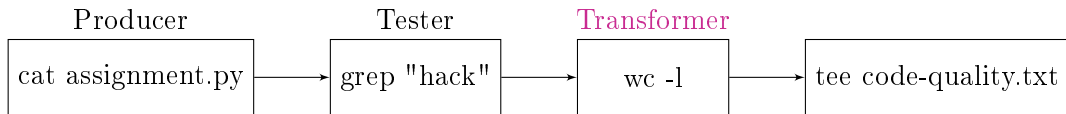


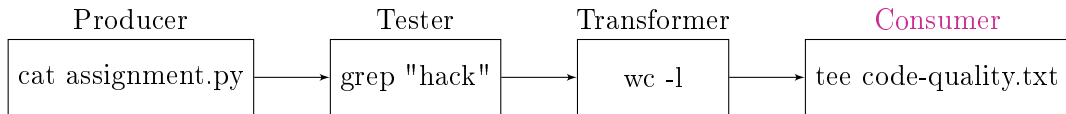
wc -l



tee code-quality.txt







*Definition 2.* One Direction Principle

Data should flow in one direction, this is the *downstream*.

*Definition 3.* Independent Filter Principle

Filters should not rely on specific upstream or downstream components.

*Corollary 1.* Generic Interface

The interface between filters should be generic.

*Corollary 2.* Composable Filters

Filters (i.e. Transformers & Testers) can be applied in any order.

*The Case Study*

Bash

*Question*

What does *BASH* stand for?



## Shell &amp; Utilities

## Utilities

admin - create and administer SCCS files (DEVELOPMENT)  
 alias - define or display aliases  
 ar - create and maintain library archives  
 asa - interpret carriage-control characters  
 at - execute commands at a later time  
 awk - pattern scanning and processing language  
 basename - return non-directory portion of a pathname  
 batch - schedule commands to be executed in a batch queue  
 bc - arbitrary-precision arithmetic language  
 bg - run jobs in the background  
 c99 - compile standard C programs  
 cal - print a calendar  
 cat - concatenate and print files  
 cd - change the working directory  
 cflow - generate a C-language flowgraph (DEVELOPMENT)  
 chgrp - change the file group ownership  
 chmod - change the file modes  
 chown - change the file ownership  
 cksum - write file checksums and sizes  
 cmp - compare two files  
 command - execute a simple command  
 comm - select or reject lines common to two files  
 compress - compress data  
 cp - copy files  
 crontab - schedule periodic background work  
 csplit - split files based on context  
 ctags - create a tags file (DEVELOPMENT, FORTRAN)  
 cut - cut out selected fields of each line of a file  
 cxref - generate a C-language program cross-reference table (DEVELOPMENT)  
 date - write the date and time  
 dd - convert and copy a file  
 delta - make a delta (change) to an SCCS file (DEVELOPMENT)  
 df - report free disk space  
 diff - compare two files  
 dirname - return the directory portion of a pathname  
 du - estimate file space usage  
 echo - write arguments to standard output  
 ed - edit text  
 env - set the environment for command invocation

ex - text editor  
 expand - convert tabs to spaces  
 expr - evaluate arguments as an expression  
 false - return false value  
 fc - process the command history list  
 fg - run jobs in the foreground  
 file - determine file type  
 find - find files  
 fold - filter for folding lines  
 fort77 - FORTRAN compiler (FORTRAN)  
 fuser - list process IDs of all processes that have one or more files open  
 gencat - generate a formatted message catalog  
 getconf - get configuration values  
 get - get a version of an SCCS file (DEVELOPMENT)  
 getopt - parse utility options  
 grep - search a file for a pattern  
 hash - remember or report utility locations  
 head - copy the first part of files  
 iconv - codeset conversion  
 id - return user identity  
 ipcrm - remove an XSI message queue, semaphore set, or shared memory segment identifier  
 ipcs - report XSI interprocess communication facilities status  
 jobs - display status of jobs in the current session  
 join - relational database operator  
 kill - terminate or signal processes  
 lex - generate programs for lexical tasks (DEVELOPMENT)  
 link - call link function  
 ln - link files  
 localedef - define locale environment  
 locale - get locale-specific information  
 logger - log messages  
 logname - return the user's login name  
 lp - send files to a printer  
 ls - list directory contents  
 m4 - macro processor  
 mailx - process messages  
 make - maintain, update, and regenerate groups of programs (DEVELOPMENT)

*Question*

Who has heard of *literate programming*?

*The Challenge — set by Jon Bently*

1. Read a file of text.
2. Determine the  $n$  most frequently used words.
3. Print out a sorted list of those words along with their frequencies.

*Knuth's Solution*

*17 pages* of elegant and descriptive code.

by Jon Bentley

with Special Guest Oysters

Don Knuth and Doug McIlroy

# programming pearls

## A LITERATE PROGRAM

Last month's column introduced Don Knuth's style of "Literate Programming" and his WEB system for building programs that are works of literature. This column presents a literate program by Knuth (its origins are sketched in last month's column) and, as befits literature, a review. So without further ado, here is Knuth's program, retypeset in Communications style.

—Jon Bentley

Common Words	Section
Introduction	1
Strategic considerations	6
Basic input routines	9
Dictionary lookup	17
The frequency counts	32
Sorting a trie	36
The endgame	41
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**1. Introduction.** The purpose of this program is to solve the following problem posed by Jon Bentley:

Given a text file and an integer  $k$ , print the  $k$  most common words in the file (and the number of their occurrences) in decreasing frequency.

Jon intentionally left the problem somewhat vague, but he stated that "a user should be able to find the 100 most frequent words in a twenty-page technical paper (roughly a 50K byte file) without undue emotional trauma."

Let us agree that a word is a sequence of one or more contiguous letters; "Bentley" is a word, but "a lot" is not. The sequence of letters should be maximal, in the sense that it cannot be lengthened without including a nonletter. Uppercase letters are considered equivalent to their lowercase counterparts, so that the words "Bentley" and "bentley" are essentially identical.

The given problem still isn't well defined, for the file might contain more than  $k$  words, all of the same

frequency, or there might not even be as many as  $k$  words. Let's be more precise: The most common words are to be printed in order of decreasing frequency, with words of equal frequency listed in alphabetical order. Printing should stop after  $k$  words have been output, if more than  $k$  words are present.

2. The input file is assumed to contain the given text. If it begins with a positive decimal number (preceded by optional blanks), that number will be the value of  $k$ ; otherwise we shall assume that  $k = 100$ . Answers will be sent to the output file.

**define** default\_# = 100 [use this value if  $k$  isn't otherwise specified]

3. Besides solving the given problem, this program is supposed to be an example of the WEB system, for people who know some Pascal but who have never seen WEB before. Here is an outline of the program to be constructed:

**program** common\_words [input, output];

**type** (Type declarations 17)

**var** (Global variables 4)

(Procedures for initialization 5)

(Procedures for input and output 9)

(Procedures for data manipulation 20)

**begin** (The main program 8);

**end**.

4. The main idea of the WEB approach is to let the program grow in natural stages, with its parts presented in roughly the order that they might have been written by a programmer who isn't especially clairvoyant.

For example, each global variable will be introduced when we first know that it is necessary or desirable; the WEB system will take care of collecting these declarations into the proper place. We already know about one global variable, namely the number that Bentley called  $k$ . Let us give it the more descriptive name `max_words_to_print`.

(Global variables 4) =  
`max_words_to_print: integer;`  
[at most this many words will be printed]

See also sections 11, 13, 18, 22, 32, and 36.  
This code is used in section 3.

5. As we introduce new global variables, we'll often want to give them certain starting values. This will be done by the `initialize` procedure, whose body will consist of various pieces of code to be specified when we think of particular kinds of initialization.

(Procedures for initialization 5) =

**procedure** initialize;

**var**  $i$ : integer; [all-purpose index for initialization]

**begin** (Set initial values 12)

**end**;

This code is used in section 3.

6. The WEB system, which may be thought of as a preprocessor for Pascal, includes a macro definition facility so that portable programs are easier to write. For example, we have already defined 'default\_# $k$ ' to be 100. Here are two more examples of WEB macros; they allow us to write, e.g., 'incr[count/p]' as a convenient abbreviation for the statement 'count[p] ← count[p] + 1'.

**define** incr(#) = # ← # + 1 [increment a variable]

**define** decr(#) = # ← # - 1 [decrement a variable]

7. Some of the procedures we shall be writing come to abrupt conclusions; hence it will be convenient to introduce a 'return' macro for the operation of jumping to the end of the procedure. A symbolic label 'exit' will be declared in all such procedures, and 'exit' will be placed just before the final end. (No other labels or goto statements are used in the present program, but the author would find it painful to eliminate these particular ones.)

**define** exit = 30 [the end of a procedure]

**define** return = goto exit [quick termination]

**format** return = nil [typeset 'return' in boldface]

8. **Strategic considerations.** What algorithms and data structures should be used for Bentley's problem? Clearly we need to be able to recognize different occurrences of the same word, so some sort of internal dictionary is necessary. There's no obvious way to decide that a particular word of the input cannot possibly be in the final set, until we've gotten very near the end of the file; so we might as well remember every word that appears.

There should be a frequency count associated with each word, and we will eventually want to run through the words in order of decreasing frequency. But there's no need to keep these counts in order as we read through the input, since the order matters only at the end.

Therefore it makes sense to structure our program as follows:

(The main program 8) =

`initialize;`

(Establish the value of `max_words_to_print` 10);

(Input the text, maintaining a dictionary with

frequency counts 24);

(Sort the dictionary by frequency 30);

(Output the results 41)

This code is used in section 3.

9. **Basic input routines.** Let's switch to a bottom-up approach now, by writing some of the procedures that we know will be necessary sooner or later. Then we'll have some confidence that our program is taking shape, even though we haven't decided yet how to handle the searching or the sorting. It will be nice to get the messy details of Pascal input out of the way and off our minds.

Here's a function that reads an optional positive integer, returning zero if none is present at the beginning of the current line.

(Procedures for input and output 9) =

**function** read\_int: integer;

**var**  $n$ : integer; [the accumulated value]

**begin**  $n \leftarrow 0$ ;

**if** eof **then**

**begin** while (not eof)  $\wedge$  (input  $\neq$  ' ') **do**

`get(input);`

**while** (input  $\neq$  '0')  $\wedge$  (input  $\neq$  '9') **do**

`begin`  $n \leftarrow 10 * n + \text{ord}(\text{input}) - \text{ord}('0')$ ;

`get(input);`

**end**;

`read_int`  $\leftarrow n$ ;

**end**;

See also sections 15, 35, and 40.

This code is used in section 3.

10. We invoke `read_int` only once.

(Establish the value of `max_words_to_print` 10) =

`max_words_to_print`  $\leftarrow$  read\_int;

**if** `max_words_to_print` = 0 **then**

`max_words_to_print`  $\leftarrow$  default\_#

This code is used in section 8.

11. To find words in the input file, we want a quick way to distinguish letters from nonletters. Pascal has

## McIlroy's Solution

```
1 tr -cs A-Za-z '\n'  
2 tr A-Z a-z |  
3 sort |  
4 uniq -c |  
5 sort -rn |  
6 sed ${1}q
```

*Question*

Is literate programming bad?

*Question*

Is literate programming bad?

*Answer*

No, the unix philosophy is just good.



## *The Unix Philosophy*

- Write programs that do one thing and do it well.

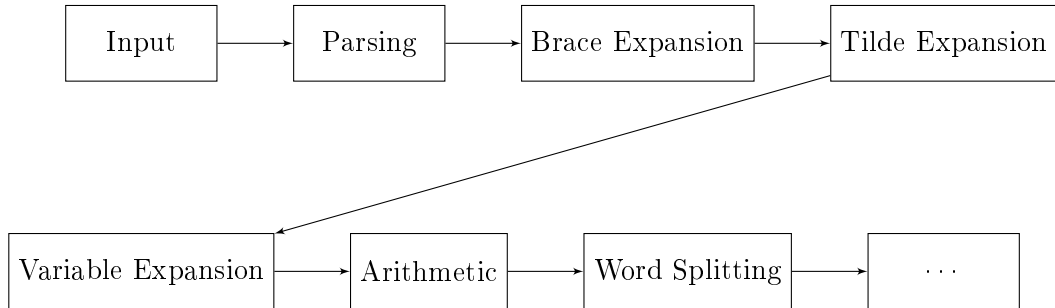
### *The Unix Philosophy*

- Write programs that do one thing and do it well.
- Write programs to work together.

### *The Unix Philosophy*

- Write programs that do one thing and do it well.
- Write programs to work together.
- Write programs to handle text streams, because that is a universal interface.

## Bash itself is a pipeline



*Case Study*

# Compilers

*Case Study*

MapReduce

*Question*

What's the advantage of the map reduce pattern?

*Question*

What's the advantage of the map reduce pattern?

*Answer*

Parallelism *[Dean and Ghemawat, 2004]*



*Question*

Using pipeline terminology, what filters do the *map* and *reduce* operators correspond to?

## References

[Dean and Ghemawat, 2004] Dean, J. and Ghemawat, S. (2004).

Mapreduce: Simplified data processing on large clusters.

In *OSDI'04: Sixth Symposium on Operating System Design and Implementation*, pages 137–150, San Francisco, CA.