

Pipeline Architecture

Software Architecture

Brae Webb

March 2, 2026

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 Architectures¹

¹sorta

Definition 0. 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 | tee code-quality.txt
```

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

Notice:

- Each program performs a small well-defined task.

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

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 | 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

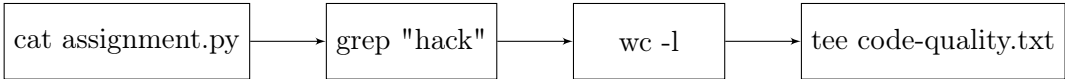
Transform data

Consumers

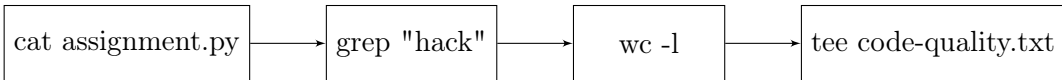
Target for results

Exercise

Label the bash pipeline



Producer



Producer

cat assignment.py



Tester

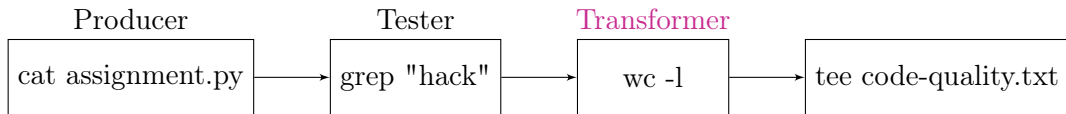
grep "hack"

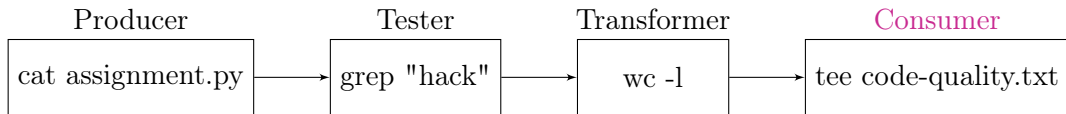


wc -l



tee code-quality.txt





Definition 0. One Direction Principle

Data should flow in one direction — *downstream*.

Definition 0. Independent Filter Principle

Filters should not rely on specific upstream or downstream components.

Corollary 0. Generic Interface

The interface between filters should be generic.

Corollary 0. Composable Filters

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

The Case Study

Bash

Shell & 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
 ipcsl - 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
Index	42

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_k* = 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*($\#$) = $\# \leftarrow \# + 1$ [increment a variable]

define *decr*($\#$) = $\# \leftarrow \# - 1$ [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 n) \wedge (input \neq ' ') **do**

get(input);

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

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

get(input);

end;

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_k*

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.

Unix Philosophy

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

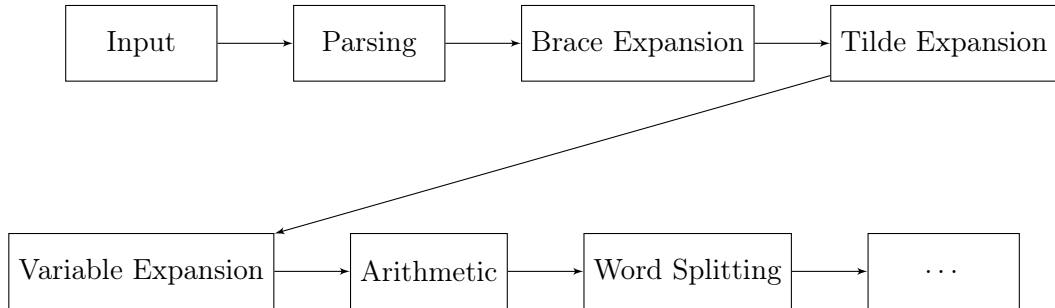
Unix Philosophy

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

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



Reading...

“Pipeline Architecture” Notes *[Webb and Thomas, 2023]*

References

[Webb and Thomas, 2023] Webb, B. and Thomas, R. (2023).
Pipeline architecture.
<https://csse6400.uqcloud.net/handouts/pipeline.pdf>.