Acme: A User Interface for Programmers

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ABSTRACT

A hybrid of window system, shell, and editor, Acme gives text-oriented applications a clean, expressive, and consistent style of interaction. Traditional window systems support interactive client programs and offer libraries of pre-defined operations such as pop-up menus and buttons to promote a consistent user interface among the clients. Acme instead provides its clients with a fixed user interface and simple conventions to encourage its uniform use. Clients access the facilities of Acme through a file system interface; Acme is in part a file server that exports device-like files that may be manipulated to access and control the contents of its windows. Written in a concurrent programming language, Acme is structured as a set of communicating processes that neatly subdivide the various aspects of its tasks: display management, input, file server, and so on.

Acme attaches distinct functions to the three mouse buttons: the left selects text; the middle executes textual commands; and the right combines context search and file opening functions to integrate the various applications and files in the system.

Acme works well enough to have developed a community that uses it exclusively. Although Acme discourages the traditional style of interaction based on typescript windows—teletypes—its users find Acme's other services render typescripts obsolete.

History and motivation

The usual typescript style of interaction with Unix and its relatives is an old one. The typescript—an intermingling of textual commands and their output—originates with the scrolls of paper on teletypes. The advent of windowed terminals has given each user what amounts to an array of teletypes, a limited and unimaginative use of the powers of bitmap displays and mice. Systems like the Macintosh that do involve the mouse as an integral part of the interaction are geared towards general users, not experts, and certainly not programmers. Software developers, at least on time-sharing systems, have been left behind.

Some programs have mouse-based editing of text files and typescripts; ones I have built include the window systems `mux` [Pike88] and `8½` [Pike91] and the text editor Sam [Pike87]. These have put the programmer's mouse to some productive work, but not wholeheartedly. Even experienced users of these programs often retype text that could be grabbed with the mouse, partly because the menu-driven interface is imperfect and partly because the various pieces are not well enough integrated.

Other programs—EMACS [Stal93] is the prime example—offer a high degree of integration but with a user interface built around the ideas of cursor-addressed terminals that date from the 1970's. They are still keyboard-intensive and dauntingly complex.

The most ambitious attempt to face these issues was the Cedar system, developed at Xerox [Swei86]. It combined a new programming language, compilers, window system, even microcode—a complete system—to construct a productive, highly integrated and interactive environment for experienced users of compiled languages. Although successful internally, the system was so large and so tied to specific hardware that it never fledged.

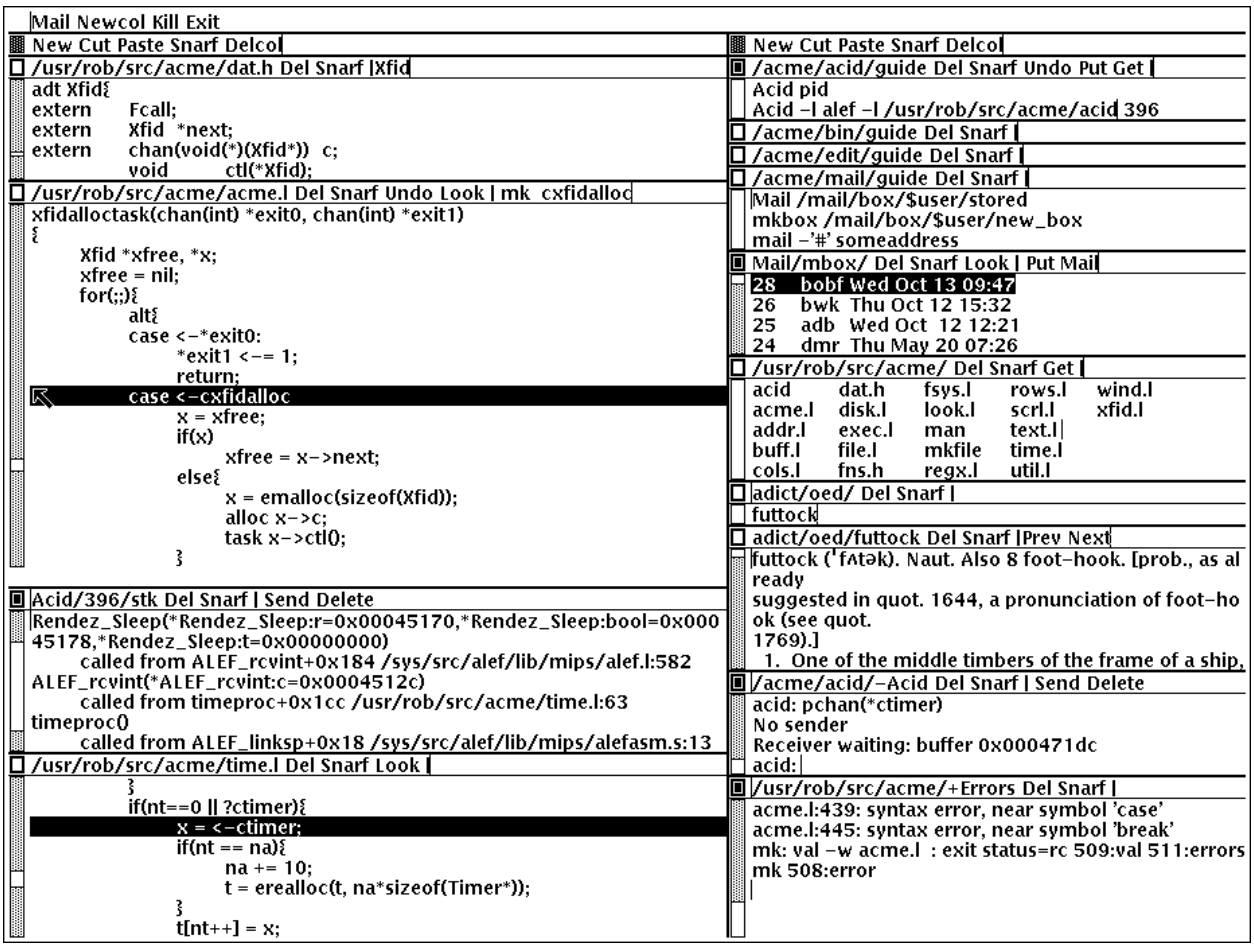

Figure 1. A small Acme screen—normally it runs on a larger display—demonstrating some of the details discussed in the text. The right column contains some guide files, a mailbox presented by Acme's mail program, the columnated display of files in Acme's own source directory, a couple of windows from the OED browser, a debugger window, and an error window showing diagnostics from a compilation. The left column holds a couple of source files (`dat.h` and `acme.l`), another debugger window displaying a stack trace, and a third source file (`time.l`). `Time.l` was opened from the debugger by clicking the right mouse button on a line in the stack window; the mouse cursor landed on the offending line of `acme.l` after a click on the compiler diagnostic.

Cedar was, however, the major inspiration for Oberon [Wirt89], a system of similar scope but much smaller scale. Through careful selection of Cedar's ideas, Oberon shows that its lessons can be a applied to a small, coherent system that can run efficiently on modest hardware. In fact, Oberon probably errs too far towards simplicity: a single-process system with weak networking, it seems an architectural throwback.

Acme is a new program, a combined window system, editor, and shell, that applies some of the ideas distilled by Oberon. Where Oberon uses objects and modules within a programming language (also called Oberon), Acme uses files and commands within an existing operating system (Plan 9). Unlike Oberon, Acme does not yet have support for graphical output, just text. At least for now, the work on Acme has concentrated on producing the smoothest user interface possible for a programmer at work.

The rest of this paper describes Acme's interface, explains how programs can access it, compares it to existing systems, and finally presents some unusual aspects of its implementation.

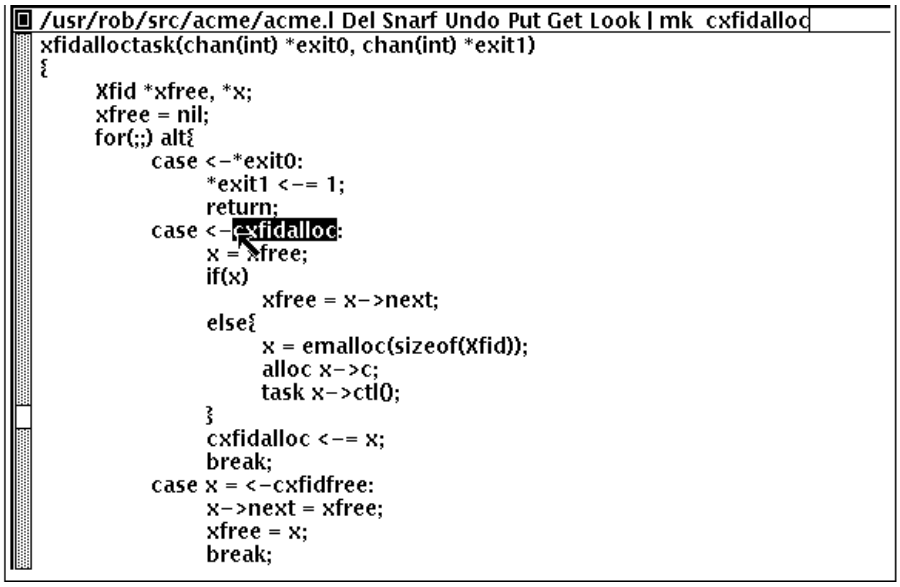

Figure 2. An Acme window showing a section of code. The upper line of text is the tag containing the file name, relevant commands, and a scratch area (right of the vertical bar); the lower portion of the window is the body, or contents, of the file. Here the scratch area contains a command for the middle button (`mk`) and a word to search for with the right button (`cxfidalloc`). The user has just clicked the right button on `cxfidalloc` and Acme has searched for the word, highlighted it, and moved the mouse cursor there. The file has been modified: the center of the layout box is black and the command `Put` appears in the tag.

User interface

Acme windows are arrayed in columns (Figure 1) and are used more dynamically than in an environment like X Windows or 8½ [Sche86, Pike91]. The system frequently creates them automatically and the user can order a new one with a single mouse button click. The initial placement of a new window is determined automatically, but the user may move an existing window anywhere by clicking or dragging a *layout box* in the upper left corner of the window.

Acme windows have two parts: a *tag* holding a single line of text, above a *body* holding zero or more lines (Figure 2). The body typically contains an image of a file being edited or the editable output of a program, analogous to an EMACS shell window. The tag contains the name of the window (usually the name of the associated file or directory), some built-in commands, and a scratch area to hold arbitrary text. If a window represents a directory, the name in the tag ends with a slash and the body contains a list of the names of the files in the directory. Finally, each non-empty body holds a scroll bar at the left of the text.

Each column of windows also has a layout box and a tag. The tag has no special meaning, although Acme pre-loads it with a few built-in commands. There is also a tag across the whole display, also loaded with helpful commands and a list of active processes started by Acme.

Typing with the keyboard and selecting with the left button are as in many other systems, including the Macintosh, 8½, and Sam. The middle and right buttons are used, somewhat like the left button, to 'sweep' text, but the indicated text is treated in a way that depends on the text's location—*context*—as well as its content. This context, based on the directory of the file containing the text, is a central component of Acme's style of interaction.

Acme has no single notion of 'current directory'. Instead, every command, file name, action, and so on is interpreted or executed in the directory named by the tag of the window containing the command. For example, the string `mammals` in a window labeled `/lib/` or `/lib/insects` will be interpreted as the file name `/lib/mammals` if such a file exists.

Throughout Acme, the middle mouse button is used to execute commands and the right mouse button is used to locate and select files and text. Even when there are no true files on which to operate—for example when editing

mail messages—Acme and its applications use consistent extensions of these basic functions. This idea is as vital to Acme as icons are to the Macintosh.

The middle button executes commands: text swept with the button pressed is underlined; when the button is released, the underline is removed and the indicated text is executed. A modest number of commands are recognized as built-ins: words like `Cut`, `Paste`, and `New` name functions performed directly by Acme. These words often appear in tags to make them always available, but the tags are not menus: any text anywhere in Acme may be a command. For example, in the tag or body of any window one may type `Cut`, select it with the left button, use the middle button to execute it, and watch it disappear again.

If the middle button indicates a command that is not recognized as a built-in, it is executed in the directory named by the tag of the window holding the text. Also, the file to be executed is searched for first in that directory. Standard input is connected to `/dev/null`, but standard and error outputs are connected to an Acme window, created if needed, called *dir*`/+Errors` where *dir* is the directory of the window. (Programs that need interactive input use a different interface, described below.) A typical use of this is to type `mk` (Plan 9's `make`) in the scratch area in the tag of a C source window, say `/sys/src/cmd/sam/regexp.c`, and execute it. Output, including compiler errors, appears in the window labeled `/sys/src/cmd/sam/+Errors`, so file names in the output are associated with the windows and directory holding the source. The `mk` command remains in the tag, serving as a sort of menu item for the associated window.

Like the middle button, the right button is used to indicate text by sweeping it out. The indicated text is not a command, however, but the argument of a generalized search operator. If the text, perhaps after appending it to the directory of the window containing it, is the name of an existing file name, Acme creates a new window to hold the file and reads it in. It then moves the mouse cursor to that window. If the file is already loaded into Acme, the mouse motion happens but no new window is made. For example, indicating the string `sam.h` in

```
#include "sam.h"
```

in a window on the file `/sys/src/cmd/sam/regexp.c` will open the file `/sys/src/cmd/sam/sam.h`.

If the file name is followed immediately by a colon and a legal address in Sam notation (for example a line number or a regular expression delimited in slashes or a comma-separated compound of such addresses), Acme highlights the target of that address in the file and places the mouse there. One may jump to line 27 of `dat.h` by indicating with the right button the text `dat.h:27`. If the file is not already open, Acme loads it. If the file name is null, for example if the indicated string is `:/^main/`, the file is assumed to be that of the window containing the string. Such strings, when typed and evaluated in the tag of a window, amount to context searches.

If the indicated text is not the name of an existing file, it is taken to be literal text and is searched for in the body of the window containing the text, highlighting the result as if it were the result of a context search.

For the rare occasion when a file name *is* just text to search for, it can be selected with the left button and used as the argument to a built-in `Look` command that always searches for literal text.

Nuances and heuristics

A user interface should not only provide the necessary functions, it should also *feel* right. In fact, it should almost not be felt at all; when one notices a user interface, one is distracted from the job at hand [Pike88]. To approach this invisibility, some of Acme's properties and features are there just to make the others easy to use. Many are based on a fundamental principle of good design: let the machine do the work.

Acme tries to avoid needless clicking and typing. There is no 'click-to-type', eliminating a button click. There are no pop-up or pull-down menus, eliminating the mouse action needed to make a menu appear. The overall design is intended to make text on the screen useful without copying or retyping; the ways in which this happens involve the combination of many aspects of the interface.

Acme tiles its windows and places them automatically to avoid asking the user to place and arrange them. For this policy to succeed, the automatic placement must behave well enough that the user is usually content with the location of a new window. The system will never get it right all the time, but in practice most windows are used at least for a while where Acme first places them. There have been several complete rewrites of the heuristics for placing a new window, and with each rewrite the system became noticeably more comfortable. The rules are as follows, although they are still subject to improvement. The window appears in the 'active' column, that most recently used

for typing or selecting. Executing and searching do not affect the choice of active column, so windows of commands and such do not draw new windows towards them, but rather let them form near the targets of their actions. Output (error) windows always appear towards the right, away from edited text, which is typically kept towards the left. Within the column, several competing desires are balanced to decide where and how large the window should be: large blank spaces should be consumed; existing text should remain visible; existing large windows should be divided before small ones; and the window should appear near the one containing the action that caused its creation.

Acme binds some actions to chords of mouse buttons. These include `Cut` and `Paste` so these common operations can be done without moving the mouse. Another is a way to apply a command in one window to text (often a file name) in another, avoiding the actions needed to assemble the command textually.

Another way Acme avoids moving the mouse is instead to move the cursor to where it is likely to be used next. When a new window is made, Acme moves the cursor to the new window; in fact, to the selected text in that window. When the user deletes a newly made window, the cursor is returned to the point it was before the window was made, reducing the irritation of windows that pop up to report annoying errors.

When a window is moved, Acme moves the cursor to the layout box in its new place, to permit further adjustment without moving the mouse. For example, when a click of the left mouse button on the layout box grows the window, the cursor moves to the new location of the box so repeated clicks, without moving the mouse, continue to grow it.

Another form of assistance the system can offer is to supply precision in pointing the mouse. The best-known form of this is ‘double-clicking’ to select a word rather than carefully sweeping out the entire word. Acme provides this feature, using context to decide whether to select a word, line, quoted string, parenthesized expression, and so on. But Acme takes the idea much further by applying it to execution and searching. A *single* click, that is, a null selection, with either the middle or right buttons, is expanded automatically to indicate the appropriate text containing the click. What is appropriate depends on the context.

For example, to execute a single-word command such as `Cut`, it is not necessary to sweep the entire word; just clicking the button once with the mouse pointing at the word is sufficient. ‘Word’ means the largest string of likely file name characters surrounding the location of the click: click on a file name, run that program. On the right button, the rules are more complicated because the target of the click might be a file name, file name with address, or just plain text. Acme examines the text near the click to find a likely file name; if it finds one, it checks that it names an existing file (in the directory named in the tag, if the name is relative) and if so, takes that as the result, after extending it with any address that may be present. If there is no file with that name, Acme just takes the largest alphanumeric string under the click. The effect is a natural overloading of the button to refer to plain text as well as file names.

First, though, if the click occurs over the left-button-selected text in the window, that text is taken to be what is indicated. This makes it easy to skip through the occurrences of a string in a file: just click the right button on some occurrence of the text in the window (perhaps after typing it in the tag) and click once for each subsequent occurrence. It isn’t even necessary to move the mouse between clicks; Acme does that. To turn a complicated command into a sort of menu item, select it: thereafter, clicking the middle button on it will execute the full command.

As an extra feature, Acme recognizes file names in angle brackets <> as names of files in standard directories of include files, making it possible for instance to look at `<stdio.h>` with a single click.

Here’s an example to demonstrate how the actions and defaults work together. Assume `/sys/src/cmd/sam/regexp.c` is open and has been edited. We write it (execute `Put` in the tag; once the file is written, Acme removes the word from the tag) and type `mk` in the tag. We execute `mk` and get some errors, which appear in a new window labeled `/sys/src/cmd/sam/+Errors`. The cursor moves automatically to that window. Say the error is

```
main.c:112: incompatible types on assignment to ‘pattern’
```

We move the mouse slightly and click the right button at the left of the error message; Acme makes a new window, reads `/sys/src/cmd/main.c` into it, selects line 112 in and places the mouse there, right on the offending line.

Coupling to existing programs

Acme's syntax for file names and addresses makes it easy for other programs to connect automatically to Acme's capabilities. For example, the output of

```
grep -n variable *.[ch]
```

can be used to help Acme step through the occurrences of a variable in a program; every line of output is potentially a command to open a file. The file names need not be absolute, either: the output appears in a window labeled with the directory in which `grep` was run, from which Acme can derive the full path names.

When necessary, we have changed the output of some programs, such as compiler error messages, to match Acme's syntax. Some might argue that it shouldn't be necessary to change old programs, but sometimes programs need to be updated when systems change, and consistent output benefits people as well as programs. A historical example is the retrofitting of standard error output to the early Unix programs when pipes were invented.

Another change was to record full path names in the symbol table of executables, so line numbers reported by the debugger are absolute names that may be used directly by Acme; it's not necessary to run the debugger in the source directory. (This aids debugging even without Acme.)

A related change was to add lines of the form

```
#pragma src "/sys/src/libregexp"
```

to header files; coupled with Acme's ability to locate a header file, this provides a fast, keyboardless way to get the source associated with a library.

Finally, Acme directs the standard output of programs it runs to windows labeled by the directory in which the program is run. Acme's splitting of the output into directory-labeled windows is a small feature that has a major effect: local file names printed by programs can be interpreted directly by Acme. By indirectly coupling the output of programs to the input, it also simplifies the management of software that occupies multiple directories.

Coupling to new programs

Like many Plan 9 programs, Acme offers a programmable interface to other programs by acting as a file server. The best example of such a file server is the window system `8½` [Pike91], which exports files with names such as `screen`, `cons`, and `mouse` through which applications may access the I/O capabilities of the windows. `8½` provides a *distinct* set of files for each window and builds a private file name space for the clients running 'in' each window; clients in separate windows see distinct files with the same names (for example `/dev/mouse`). Acme, like the process file system [PPTTW93], instead associates each window with a directory of files; the files of each window are visible to any application. This difference reflects a difference in how the systems are used: `8½` tells a client what keyboard and mouse activity has happened in its window; Acme tells a client what changes that activity wrought on any window it asks about. Putting it another way, `8½` enables the construction of interactive applications; Acme provides the interaction for applications.

The root of Acme's file system is mounted using Plan 9 operations on the directory `/mnt/acme`. In that root directory appears a directory for each window, numbered with the window's identifier, analogous to a process identifier, for example `/mnt/acme/27`. The window's directory contains 6 files: `/mnt/acme/27/addr`, `body`, `ctl`, `data`, `event`, and `tag`. The `body` and `tag` files contain the text of the respective parts of the window; they may be read to recover the contents. Data written to these files is appended to the text; `seeks` are ignored. The `addr` and `data` files provide random access to the contents of the body. The `addr` file is written to set a character position within the body; the `data` file may then be read to recover the contents at that position, or written to change them. (The tag is assumed small and special-purpose enough not to need special treatment. Also, `addr` indexes by character position, which is not the same as byte offset in Plan 9's multi-byte character set [Pike93]). The format accepted by the `addr` file is exactly the syntax of addresses within the user interface, permitting regular expressions, line numbers, and compound addresses to be specified. For example, to replace the contents of lines 3 through 7, write the text

```
3,7
```

to the `addr` file, then write the replacement text to the `data` file. A zero-length write deletes the addressed text; further writes extend the replacement.

The control file, `ctl`, may be written with commands to effect actions on the window; for example the command

```
name /adm/users
```

sets the name in the tag of the window to `/adm/users`. Other commands allow deleting the window, writing it to a file, and so on. Reading the `ctl` file recovers a fixed-format string containing 5 textual numbers—the window identifier, the number of characters in the tag, the number in the body, and some status information—followed by the text of the tag, up to a newline.

The last file, `event`, is the most unusual. A program reading a window's `event` file is notified of all changes to the text of the window, and is asked to interpret all middle- and right-button actions. The data passed to the program is fixed-format and reports the source of the action (keyboard, mouse, external program, etc.), its location (what was pointed at or modified), and its nature (change, search, execution, etc.). This message, for example,

```
MI15 19 0 4 time
```

reports that actions of the mouse (`M`) inserted in the body (capital `I`) the 4 characters of `time` at character positions 15 through 19; the zero is a flag word. Programs may apply their own interpretations of searching and execution, or may simply reflect the events back to Acme, by writing them back to the `event` file, to have the default interpretation applied. Some examples of these ideas in action are presented below.

Notice that changes to the window are reported after the fact; the program is told about them but is not required to act on them. Compare this to a more traditional interface in which a program is told, for example, that a character has been typed on the keyboard and must then display and interpret it. Acme's style stems from the basic model of the system, in which any number of agents—the keyboard, mouse, external programs writing to `data` or `body`, and so on—may change the contents of a window. The style is efficient: many programs are content to have Acme do most of the work and act only when the editing is completed. An example is the Acme mail program, which can ignore the changes made to a message being composed and just read its body when asked to send it. A disadvantage is that some traditional ways of working are impossible. For example, there is no way 'to turn off echo': characters appear on the screen and are read from there; no agent or buffer stands between the keyboard and the display.

There are a couple of other files made available by Acme in its root directory rather than in the directory of each window. The text file `/mnt/acme/index` holds a list of all window names and numerical identifiers, somewhat analogous to the output of the `ps` command for processes. The most important, though, is `/mnt/acme/new`, a directory that makes new windows, similar to the `clone` directory in the Plan 9 network devices [Pres93]. The act of opening any file in `new` creates a new Acme window; thus the shell command

```
grep -n var *.c > /mnt/acme/new/body
```

places its output in the body of a fresh window. More sophisticated applications may open `new/ctl`, read it to discover the new window's identifier, and then open the window's other files in the numbered directory.

Acme-specific programs

Although Acme is in part an attempt to move beyond typescripts, they will probably always have utility. The first program written for Acme was therefore one to run a shell or other traditional interactive application in a window, the Acme analog of `xterm`. This program, `win`, has a simple structure: it acts as a two-way intermediary between Acme and the shell, cross-connecting the standard input and output of the shell to the text of the window. The style of interaction is modeled after `mux` [Pike88]: standard output is added to the window at the *output point;* text typed after the output point is made available on standard input when a newline is typed. After either of these actions, the output point is advanced. This is different from the working of a regular terminal, permitting cut-and-paste editing of an input line until the newline is typed. Arbitrary editing may be done to any text in the window. The implementation of `win`, using the `event`, `addr`, and `data` files, is straightforward. `Win` needs no code for handling the keyboard and mouse; it just monitors the contents of the window. Nonetheless, it allows Acme's full editing to be applied to shell commands. The division of labor between `win` and `Acme` contrasted with `xterm` and the X server demonstrates how much work Acme handles automatically. `Win` is implemented by a single source file 560 lines long and has no graphics code.

`Win` uses the middle and right buttons to connect itself in a consistent way with the rest of Acme. The middle button still executes commands, but in a style more suited to typescripts. Text selected with the middle button is treated as if it had been typed after the output point, much as a similar feature in `xterm` or 8½, and therefore causes it to be 'executed' by the application running in the window. Right button actions are reflected back to Acme but refer to the appropriate files because `win` places the name of the current directory in the tag of the window. If the shell is running, a simple shell function replacing the `cd` command can maintain the tag as the shell navigates the file system. This means, for example, that a right button click on a file mentioned in an `ls` listing opens the file within Acme.

Another Acme-specific program is a mail-reader that begins by presenting, in a window, a listing of the messages in the user's mailbox, one per line. Here the middle and right button actions are modified to refer to mail commands and messages, but the change feels natural. Clicking the right button on a line creates a new window and displays the message there, or, if it's already displayed, moves the mouse to that window. The metaphor is that the mailbox is a directory whose constituent files are messages. The mail program also places some relevant commands in the tag lines of the windows; for example, executing the word `Reply` in a message's tag creates a new window in which to compose a message to the sender of the original; `Post` then dispatches it. In such windows, the addressee is just a list of names on the first line of the body, which may be edited to add or change recipients. The program also monitors the mailbox, updating the 'directory' as new messages arrive.

The mail program is as simple as it sounds; all the work of interaction, editing, and management of the display is done by Acme. The only difficult sections of the 1200 lines of code concern honoring the external protocols for managing the mailbox and connecting to `sendmail`.

One of the things Acme does not provide directly is a facility like Sam's command language to enable actions such as global substitution; within Acme, all editing is done manually. It is easy, though, to write external programs for such tasks. In this, Acme comes closer to the original intent of Oberon: a directory, `/acme/edit`, contains a set of tools for repetitive editing and a template or 'guide' file that gives examples of its use. Acme's editing guide, `/acme/edit/guide`, looks like this:

```
e file | x '/regexp/' | c 'replacement'
e file:'0,$' | x '/.*word.*\n/' | p -n
e file | pipe command args ...
```

The syntax is reminiscent of Sam's command language, but here the individual one-letter commands are all standalone programs connected by pipes. Passed along the pipes are addresses, analogous to structural expressions in Sam terminology. The `e` command, unlike that of Sam, starts the process by generating the address (default dot, the highlighted selection) in the named files. The other commands are as in Sam: `p` prints the addressed text on standard output (the `-n` option is analogous to that of `grep`, useful in combination with the right mouse button), `x` matches a regular expression to the addressed (incoming) text, subdividing the text, `c` replaces the text, and so on. Thus, global substitution throughout a file, which would be expressed in Sam as

```
0,$ x/regexp/ c/replacement/
```

in Acme's editor becomes

```
e 'file:0,$' | x '/regexp/' | c 'replacement'
```

To use the Acme editing commands, open `/acme/edit/guide`, use the mouse and keyboard to edit one of the commands to the right form, and execute it with the middle button. Acme's context rules find the appropriate binaries in `/acme/edit` rather than `/bin`; the effect is to turn `/acme/edit` into a toolbox containing tools and instructions (the guide file) for their use. In fact, the source for these tools is also there, in the directory `/acme/edit/src`. This setup allows some control of the file name space for binary programs; not only does it group related programs, it permits the use of common names for uncommon jobs. For example, the single-letter names would be unwise in a directory in everyone's search path; here they are only visible when running editing commands.

In Oberon, such a collection would be called a *tool* and would consist of a set of entry points in a module and a menu-like piece of text containing representative commands that may be edited to suit and executed. There is, in fact, a tool called `Edit` in Oberon. To provide related functionality, Acme exploits the directory and file structure of the underlying system, rather than the module structure of the language; this fits well with Plan 9's file-oriented

philosophy. Such tools are central to the working of Oberon but they are less used in Acme, at least so far. The main reason is probably that Acme's program interface permits an external program to remain executing in the background, providing its own commands as needed (for example, the `Reply` command in the mail program); Oberon uses tools to implement such services because its must invoke a fresh program for each command. Also, Acme's better integration allows more basic functions to be handled internally; the right mouse button covers a lot of the basic utility of the editing tools in Oberon. Nonetheless, as more applications are written for Acme, many are sure to take this Oberon tool-like form.

Comparison with other systems

Acme's immediate ancestor is Help [Pike92], an experimental system written a few years ago as a first try at exploring some of Oberon's ideas in an existing operating system. Besides much better engineering, Acme's advances over Help include the actions of the right button (Help had nothing comparable), the ability to connect long-running programs to the user interface (Help had no analog of the `event` file), and the small but important change to split command output into windows labeled with the directory in which the commands run.

Most of Acme's style, however, derives from the user interface and window system of Oberon [Wirt89, Reis91]. Oberon includes a programming language and operating system, which Acme instead borrows from an existing system, Plan 9. When I first saw Oberon, in 1988, I was struck by the simplicity of its user interface, particularly its lack of menus and its elegant use of multiple mouse buttons. The system seemed restrictive, though—single process, single language, no networking, event-driven programming—and failed to follow through on some of its own ideas. For example, the middle mouse button had to be pointed accurately and the right button was essentially unused. Acme does follow through: to the basic idea planted by Oberon, it adds the ability to run on different operating systems and hardware, connection to existing applications including interactive ones such as shells and debuggers, support for multiple processes, the right mouse button's features, the default actions and context-dependent properties of execution and searching, and a host of little touches such as moving the mouse cursor that make the system more pleasant. At the moment, though, Oberon does have one distinct advantage: it incorporates graphical programs well into its model, an issue Acme has not yet faced.

Acme shares with the Macintosh a desire to use the mouse well and it is worth comparing the results. The mouse on the Macintosh has a single button, so menus are essential and the mouse must frequently move a long way to reach the appropriate function. An indication that this style has trouble is that applications provide keyboard sequences to invoke menu selections and users often prefer them. A deeper comparison is that the Macintosh uses pictures where Acme uses text. In contrast to pictures, text can be edited quickly, created on demand, and fine-tuned to the job at hand; consider adding an option to a command. It is also self-referential; Acme doesn't need menus because any text can be in effect a menu item. The result is that, although a Macintosh screen is certainly prettier and probably more attractive, especially to beginners, an Acme screen is more dynamic and expressive, at least for programmers and experienced users.

For its role in the overall system, Acme most resembles EMACS [Stal93]. It is tricky to compare Acme to EMACS, though, because there are many versions of EMACS and, since it is fully programmable, EMACS can in principle do anything Acme does. Also, Acme is much younger and therefore has not had the time to acquire as many features. The issue therefore is less what the systems can be programmed to do than how they are used. The EMACS versions that come closest to Acme's style are those that have been extended to provide a programming environment, usually for a language such as LISP [Alle92, Lucid92]. For richness of the existing interface, these EMACS versions are certainly superior to Acme. On the other hand, Acme's interface works equally well already for a variety of languages; for example, one of its most enthusiastic users works almost exclusively in Standard ML, a language nothing like C.

Where Acme excels is in the smoothness of its interface. Until recently, EMACS did not support the mouse especially well, and even with the latest version providing features such as 'extents' that can be programmed to behave much like Acme commands, many users don't bother to upgrade. Moreover, in the versions that provide extents, most EMACS packages don't take advantage of them.

The most important distinction is just that EMACS is fundamentally keyboard-based, while Acme is mouse-based.

People who try Acme find it hard to go back to their previous environment. Acme automates so much that to return to a traditional interface is to draw attention to the extra work it requires.

Concurrency in the implementation

Acme is about 8,000 lines of code in Alef, a concurrent object-oriented language syntactically similar to C [ALEF]. Acme's structure is a set of communicating processes in a single address space. One subset of the processes drives the display and user interface, maintaining the windows; other processes forward mouse and keyboard activity and implement the file server interface for external programs. The language and design worked out well; as explained elsewhere [Pike89, Gans93], user interfaces built with concurrent systems can avoid the clumsy top-level event loop typical of traditional interactive systems.

An example of the benefits of the multi-process style is the management of the state of open files held by clients of the file system interface. The problem is that some I/O requests, such as reading the `event` file, may block if no data is available, and the server must maintain the state of (possibly many) requests until data appears. For example, in 8½, a single-process window system written in C, pending requests were queued in a data structure associated with each window. After activity in the window that might complete pending I/O, the data structure was scanned for requests that could now finish. This structure did not fit well with the rest of the program and, worse, required meticulous effort to guarantee correct behavior under all conditions (consider raw mode, reads of partial lines, deleting a window, multibyte characters, etc.).

Acme instead creates a new dedicated process for each I/O request. This process coordinates with the rest of the system using Alef's synchronous communication; its state implicitly encodes the state of the I/O request and obviates the need for queuing. The passage of the request through Acme proceeds as follows.

Acme contains a file server process, F, that executes a `read` system call to receive a Plan 9 file protocol (9P) message from the client [AT&T92]. The client blocks until Acme answers the request. F communicates with an allocation process, M, to acquire an object of type `Xfid` ('executing fid'; fid is a 9P term) to hold the request. M sits in a loop (reproduced in Figure 2) waiting for either a request for a new `Xfid` or notification that an existing one has finished its task. When an `Xfid` is created, an associated process, X, is also made. M queues idle `Xfids`, allocating new ones only when the list is empty. Thus, there is always a pool of `Xfids`, some executing, some idle.

The `Xfid` object contains a channel, `Xfid.c`, for communication with its process; the unpacked message; and some associated functions, mostly corresponding to 9P messages such as `Xfid.write` to handle a 9P write request.

The file server process F parses the message to see its nature—open, close, read, write, etc. Many messages, such as directory lookups, can be handled immediately; these are responded to directly and efficiently by F without invoking the `Xfid`, which is therefore maintained until the next message. When a message, such as a write to the display, requires the attention of the main display process and interlocked access to its data structures, F enables X by sending a function pointer on `Xfid.c`. For example, if the message is a write, F executes

```
x->c <-= Xfid.write;
```

which sends the address of `Xfid.write` on `Xfid.c`, waking up X.

The `Xfid` process, X, executes a simple loop:

```
void
Xfid.ctl(Xfid *x)
{
        for(;;){
                (*<-x->c)(x);   /* receive and execute message */
                bflush();       /* synchronize bitmap display */
                cxfidfree <-= x;        /* return to free list */
        }
}
```

Thus X will wake up with the address of a function to call (here `Xfid.write`) and execute it; once that completes, it returns itself to the pool of free processes by sending its address back to the allocator.

Although this sequence may seem complicated, it is just a few lines of code and is in fact far simpler than the management of the I/O queues in 8½. The hard work of synchronization is done by the Alef run time system. Moreover, the code worked the first time, which cannot be said for the code in 8½.

Undo

Acme provides a general undo facility like that of Sam, permitting textual changes to be unwound arbitrarily. The implementation is superior to Sam's, though, with much higher performance and the ability to 'redo' changes.

Sam uses a multi-pass algorithm that builds a transcript of changes to be made simultaneously and then executes them atomically. This was thought necessary because the elements of a repetitive command such as a global substitution should all be applied to the same initial file and implemented simultaneously; forming the complete transcript before executing any of the changes avoids the cumbersome management of addresses in a changing file. Acme, however, doesn't have this problem; global substitution is controlled externally and may be made incrementally by exploiting an observation: if the changes are sorted in address order and executed in reverse, changes will not invalidate the addresses of pending changes.

Acme therefore avoids the initial transcript. Instead, changes are applied directly to the file, with an undo transcript recorded in a separate list. For example, when text is added to a window, it is added directly and a record of what to delete to restore the state is appended to the undo list. Each undo action and the file are marked with a sequence number; actions with the same sequence number are considered a unit to be undone together. The invariant state of the structure is that the last action in the undo list applies to the current state of the file, even if that action is one of a related set from, for example, a global substitute. (In Sam, a related set of actions needed to be undone simultaneously.) To undo an action, pop the last item on the undo list, apply it to the file, revert it, and append it to a second, redo list. To redo an action, do the identical operation with the lists interchanged. The expensive operations occur only when actually undoing; in normal editing the overhead is minor. For example, Acme reads files about seven times faster than Sam, partly because of this improvement and partly because of a cleaner implementation.

Acme uses a temporary file to hold the text, keeping in memory only the visible portion, and therefore can edit large files comfortably even on small-memory machines such as laptops.

Future

Acme is still under development. Some things are simply missing. For example, Acme should support non-textual graphics, but this is being deferred until it can be done using a new graphics model being developed for Plan 9. Also, it is undecided how Acme's style of interaction should best be extended to graphical applications. On a smaller scale, although the system feels smooth and comfortable, work continues to tune the heuristics and try new ideas for the user interface.

There need to be more programs that use Acme. Browsers for Usenet and AP News articles, the Oxford English Dictionary, and other such text sources exist, but more imaginative applications will be necessary to prove that Acme's approach is viable. One that has recently been started is an interface to the debugger Acid [Wint94], although it is still unclear what form it will ultimately take.

Acme shows that it is possible to make a user interface a stand-alone component of an interactive environment. By absorbing more of the interactive functionality than a simple window system, Acme off-loads much of the computation from its applications, which helps keep them small and consistent in their interface. Acme can afford to dedicate considerable effort to making that interface as good as possible; the result will benefit the entire system.

Acme is complete and useful enough to attract users. Its comfortable user interface, the ease with which it handles multiple tasks and programs in multiple directories, and its high level of integration make it addictive. Perhaps most telling, Acme shows that typescripts may not be the most productive interface to a time-sharing system.

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Biography

Rob Pike, well known for his appearances on ‘‘Late Night with David Letterman’’, is also a Member of Technical Staff at AT&T Bell Laboratories in Murray Hill, New Jersey, where he has been since 1980, the same year he won the Olympic silver medal in Archery. In 1981 he wrote the first bitmap window system for Unix systems, and has since written ten more. With Bart Locanthi he designed the Blit terminal; with Brian Kernighan he wrote *The Unix Programming Environment.* A shuttle mission nearly launched a gamma-ray telescope he designed. He is a Canadian citizen and has never written a program that uses cursor addressing.