THE CATHEDRAL AND THE BAZAAR [excerpts]

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Linux is subversive. Who would have thought even five years ago (1991) that a world-class operating system could coalesce as if by magic out of part-time hacking by several thousand developers scattered all over the planet, connected only by the tenuous strands of the Internet?

Certainly not I. By the time Linux swam onto my radar screen in early 1993, I had already been involved in Unix and open-source development for ten years. I was one of the first GNU contributors in the mid-1980s. I had released a good deal of open-source software onto the net, developing or co-developing several programs (nethack, Emacs's VC and GUD modes, xlife, and others) that are still in wide use today. I thought I knew how it was done.

Linux overturned much of what I thought I knew. I had been preaching the Unix gospel of small tools, rapid prototyping and evolutionary programming for years. But I also believed there was a certain critical complexity above which a more centralized, a priori approach was required. I believed that the most important software (operating systems and really large tools like the Emacs programming editor) needed to be built like cathedrals, carefully crafted by individual wizards or small bands of mages working in splendid isolation, with no beta to be released before its time.

Linus Torvalds's style of development—release early and often, delegate everything you can, be open to the point of promiscuity—came as a surprise. No quiet, reverent cathedral-building here—rather, the Linux community seemed to resemble a great babbling bazaar of differing agendas and approaches (aptly symbolized by the Linux archive sites, who'd take submissions from *anyone*) out of which a coherent and stable system could seemingly emerge only by a succession of miracles.

The fact that this bazaar style seemed to work, and work well, came as a distinct shock. As I learned my way around, I worked hard not just at individual projects, but also at trying to understand why the Linux world not only didn't fly apart in confusion but seemed to go from strength to strength at a speed barely imaginable to cathedral-builders.

By mid-1996 I thought I was beginning to understand. Chance handed me a perfect way to test my theory, in the form of an open-source project that I could consciously try to run in the bazaar style. So I did—and it was a significant success.

This is the story of that project. I'll use it to propose some aphorisms about effective open-source development. Not all of these are things I first learned in the Linux world, but we'll see how the Linux world gives them particular point. If I'm correct, they'll help you understand exactly what it is that makes the Linux community such a fountain of good software—and, perhaps, they will help you become more productive yourself.

The Mail Must Get Through

Since 1993 I'd been running the technical side of a small free-access Internet service provider called Chester County InterLink (CCIL) in West Chester, Pennsylvania. I co-founded CCIL and wrote our unique multiuser bulletin-board software—you can check it out by telnetting to locke.ccil.org. Today it supports almost three thousand users on thirty lines. The job allowed me 24-hour-a-day access to the net through CCIL's 56K line—in fact, the job practically demanded it!

I had gotten quite used to instant Internet email. I found having to periodically telnet over to locke to check my mail annoying. What I wanted was for my mail to be delivered on snark (my home system) so that I would be notified when it arrived and could handle it using all my local tools.

The Internet's native mail forwarding protocol, SMTP (Simple Mail Transfer Protocol), wouldn't suit, because it works best when machines are connected full-time, while my personal machine isn't always on the Internet, and doesn't have a static IP address. What I needed was a program that would reach out over my intermittent dialup connection and pull across my mail to be delivered locally. I knew such things existed, and that most of them used a simple application protocol called POP (Post Office Protocol). POP is now widely supported by most common mail clients, but at the time, it wasn't built in to the mail reader I was using.

I needed a POP3 client. So I went out on the Internet and found one. Actually, I found three or four. I used one of them for a while, but it was missing what seemed an obvious feature, the ability to hack the addresses on fetched mail so replies would work properly.

The problem was this: suppose someone named `joe' on locke sent me mail. If I fetched the mail to snark and then tried to reply to it, my mailer would cheerfully try to ship it to a nonexistent `joe' on snark. Hand-editing reply addresses to tack on <@ccil.org> quickly got to be a serious pain.

This was clearly something the computer ought to be doing for me. But none of the existing POP clients knew how! And this brings us to the first lesson:

1. Every good work of software starts by scratching a developer's personal itch.

Perhaps this should have been obvious (it's long been proverbial that ``Necessity is the mother of invention'') but too often software developers spend their days grinding away for pay at programs they neither need nor love. But not in the Linux world—which may explain why the average quality of software originated in the Linux community is so high.

So, did I immediately launch into a furious whirl of coding up a brand-new POP3 client to compete with the existing ones? Not on your life! I looked carefully at the POP utilities I had in hand, asking myself ``Which one is closest to what I want?'' Because:

2. Good programmers know what to write. Great ones know what to rewrite (and reuse).

While I don't claim to be a great programmer, I try to imitate one. An important trait of the great ones is constructive laziness. They know that you get an A not for effort but for results, and that it's almost always easier to start from a good partial solution than from nothing at all.

Linus Torvalds, for example, didn't actually try to write Linux from scratch. Instead, he started by reusing code and ideas from Minix, a tiny Unix-like operating system for PC clones. Eventually all the Minix code went away or was completely rewritten—but while it was there, it provided scaffolding for the infant that would eventually become Linux.

In the same spirit, I went looking for an existing POP utility that was reasonably well coded, to use as a development base.

The source-sharing tradition of the Unix world has always been friendly to code reuse (this is why the GNU project chose Unix as a base OS, in spite of serious reservations about the OS itself). The Linux world has taken this tradition nearly to its technological limit; it has terabytes of open sources generally available. So spending time looking for some else's almost-good-enough is more likely to give you good results in the Linux world than anywhere else.

And it did for me. With those I'd found earlier, my second search made up a total of nine candidates—fetchpop, PopTart, get-mail, gwpop, pimp, pop-perl, popc, popmail and upop. The one I first settled on was `fetchpop' by Seung-Hong Oh. I put my header-rewrite feature in it, and made various other improvements which the author accepted into his 1.9 release.

A few weeks later, though, I stumbled across the code for popclient by Carl Harris, and found I had a problem. Though fetchpop had some good original ideas in it (such as its background-daemon mode), it could only handle POP3 and was rather amateurishly coded (Seung-Hong was at that time a bright but inexperienced programmer, and both traits showed). Carl's code was better, quite professional and solid, but his program lacked several important and rather tricky-to-implement fetchpop features (including those I'd coded myself).

Stay or switch? If I switched, I'd be throwing away the coding I'd already done in exchange for a better development base.

A practical motive to switch was the presence of multiple-protocol support. POP3 is the most commonly used of the post-office server protocols, but not the only one. Fetchpop and the other competition didn't do POP2, RPOP, or APOP, and I was already having vague thoughts of perhaps adding IMAP (Internet Message Access Protocol, the most recently designed and most powerful post-office protocol) just for fun.

But I had a more theoretical reason to think switching might be as good an idea as well, something I learned long before Linux.

> 3. ``Plan to throw one away; you will, anyhow.'' (Fred Brooks, *The Mythical Man-Month*, Chapter 11)

Or, to put it another way, you often don't really understand the problem until after the first time you implement a solution. The second time, maybe you know enough to do it right. So if you want to get it right, be ready to start over *at least* once [JB].

Well (I told myself) the changes to fetchpop had been my first try. So I switched.

After I sent my first set of popclient patches to Carl Harris on 25 June 1996, I found out that he had basically lost interest in popclient some time before. The code was a bit dusty, with minor bugs hanging out. I had many changes to make, and we quickly agreed that the logical thing for me to do was take over the program.

Without my actually noticing, the project had escalated. No longer was I just contemplating minor patches to an existing POP client. I took on maintaining an entire one, and there were ideas bubbling in my head that I knew would probably lead to major changes.

In a software culture that encourages code-sharing, this is a natural way for a project to evolve. I was acting out this principle:

> 4. If you have the right attitude, interesting problems will find you.

But Carl Harris's attitude was even more important. He understood that

> 5. When you lose interest in a program, your last duty to it is to hand it off to a competent successor.

Without ever having to discuss it, Carl and I knew we had a common goal of having the best solution out there. The only question for either of us was whether I could establish that I was a safe pair of hands. Once I did that, he acted with grace and dispatch. I hope I will do as well when it comes my turn.

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Necessary Preconditions for the Bazaar Style

Early reviewers and test audiences for this essay consistently raised questions about the preconditions for successful bazaar-style development, including both the qualifications of the project leader and the state of code at the time one goes public and starts to try to build a co-developer community.

It's fairly clear that one cannot code from the ground up in bazaar style [IN]. One can test, debug and improve in bazaar style, but it would be very hard to *originate* a project in bazaar mode. Linus didn't try it. I didn't either. Your nascent developer community needs to have something runnable and testable to play with.

When you start community-building, what you need to be able to present is a *plausible promise*. Your program doesn't have to work particularly well. It can be crude, buggy, incomplete, and poorly documented. What it must not fail to do is (a) run, and (b) convince potential co-developers that it can be evolved into something really neat in the foreseeable future.

Linux and fetchmail both went public with strong, attractive basic designs. Many people thinking about the bazaar model as I have presented it have correctly considered this critical, then jumped from that to the conclusion that a high degree of design intuition and cleverness in the project leader is indispensable.

But Linus got his design from Unix. I got mine initially from the ancestral popclient (though it would later change a great deal, much more proportionately speaking than has Linux). So does the leader/coordinator for a bazaar-style effort really have to have exceptional design talent, or can he get by through leveraging the design talent of others?

I think it is not critical that the coordinator be able to originate designs of exceptional brilliance, but it is absolutely critical that the coordinator be able to *recognize good design ideas from others*.

Both the Linux and fetchmail projects show evidence of this. Linus, while not (as previously discussed) a spectacularly original designer, has displayed a powerful knack for recognizing good design and integrating it into the Linux kernel. And I have already described how the single most powerful design idea in fetchmail (SMTP forwarding) came from somebody else.

Early audiences of this essay complimented me by suggesting that I am prone to undervalue design originality in bazaar projects because I have a lot of it myself, and therefore take it for granted. There may be some truth to this; design (as opposed to coding or debugging) is certainly my strongest skill.

But the problem with being clever and original in software design is that it gets to be a habit—you start reflexively making things cute and complicated when you should be keeping them robust and simple. I have had projects crash on me because I made this mistake, but I managed to avoid this with fetchmail.

So I believe the fetchmail project succeeded partly because I restrained my tendency to be clever; this argues (at least) against design originality being essential for successful bazaar projects. And consider Linux. Suppose Linus Torvalds had been trying to pull off fundamental innovations in operating system design during the development; does it seem at all likely that the resulting kernel would be as stable and successful as what we have?

A certain base level of design and coding skill is required, of course, but I expect almost anybody seriously thinking of launching a bazaar effort will already be above that minimum. The open-source community's internal market in reputation exerts subtle pressure on people not to launch development efforts they're not competent to follow through on. So far this seems to have worked pretty well.

There is another kind of skill not normally associated with software development which I think is as important as design cleverness to bazaar projects—and it may be more important. A bazaar project coordinator or leader must have good people and communications skills.

This should be obvious. In order to build a development community, you need to attract people, interest them in what you're doing, and keep them happy about the amount of work they're doing. Technical sizzle will go a long way towards accomplishing this, but it's far from the whole story. The personality you project matters, too.

It is not a coincidence that Linus is a nice guy who makes people like him and want to help him. It's not a coincidence that I'm an energetic extrovert who enjoys working a crowd and has some of the delivery and instincts of a stand-up comic. To make the bazaar model work, it helps enormously if you have at least a little skill at charming people.

The Social Context of Open-Source Software

It is truly written: the best hacks start out as personal solutions to the author's everyday problems, and spread because the problem turns out to be typical for a large class of users. This takes us back to the matter of rule 1, restated in a perhaps more useful way:

18. To solve an interesting problem, start by finding a problem that is interesting to you.

So it was with Carl Harris and the ancestral popclient, and so with me and fetchmail. But this has been understood for a long time. The interesting point, the point that the histories of Linux and fetchmail seem to demand we focus on, is the next stage—the evolution of software in the presence of a large and active community of users and co-developers.

In *The Mythical Man-Month*, Fred Brooks observed that programmer time is not fungible; adding developers to a late software project makes it later. As we've seen previously, he argued that the complexity and communication costs of a project rise with the square of the number of developers, while work done only rises linearly. Brooks's Law has been widely regarded as a truism. But we've examined in this essay an number of ways in which the process of open-source development falsifies the assumptionms behind it—and, empirically, if Brooks's Law were the whole picture Linux would be impossible.

Gerald Weinberg's classic *The Psychology of Computer Programming* supplied what, in hindsight, we can see as a vital correction to Brooks. In his discussion of ``egoless programming'', Weinberg observed that in shops where developers are not territorial about their code, and encourage other people to look for bugs and potential improvements in it, improvement happens dramatically faster than elsewhere. (Recently, Kent Beck's `extreme programming' technique of deploying coders in pairs looking over one anothers' shoulders might be seen as an attempt to force this effect.)

Weinberg's choice of terminology has perhaps prevented his analysis from gaining the acceptance it deserved—one has to smile at the thought of describing Internet hackers as ``egoless''. But I think his argument looks more compelling today than ever.

The bazaar method, by harnessing the full power of the ``egoless programming'' effect, strongly mitigates the effect of Brooks's Law. The principle behind Brooks's Law is not repealed, but given a large developer population and cheap communications its effects can be swamped by competing nonlinearities that are not otherwise visible. This resembles the relationship between Newtonian and Einsteinian physics—the older system is still valid at low energies, but if you push mass and velocity high enough you get surprises like nuclear explosions or Linux.

The history of Unix should have prepared us for what we're learning from Linux (and what I've verified experimentally on a smaller scale by deliberately copying Linus's methods [EGCS]). That is, while coding remains an essentially solitary activity, the really great hacks come from harnessing the attention and brainpower of entire communities. The developer who uses only his or her own brain in a closed project is going to fall behind the developer who knows how to create an open, evolutionary context in which feedback exploring the design space, code contributions, bug-spotting, and other improvements come from from hundreds (perhaps thousands) of people.

But the traditional Unix world was prevented from pushing this approach to the ultimate by several factors. One was the legal contraints of various licenses, trade secrets, and commercial interests. Another (in hindsight) was that the Internet wasn't yet good enough.

Before cheap Internet, there were some geographically compact communities where the culture encouraged Weinberg's ``egoless'' programming, and a developer could easily attract a lot of skilled kibitzers and co-developers. Bell Labs, the MIT AI and LCS labs, UC Berkeley—these became the home of innovations that are legendary and still potent.

Linux was the first project for which a conscious and successful effort to use the entire *world* as its talent pool was made. I don't think it's a coincidence that the gestation period of Linux coincided with the birth of the World Wide Web, and that Linux left its infancy during the same period in 1993–1994 that saw the takeoff of the ISP industry and the explosion of mainstream interest in the Internet. Linus was the first person who learned how to play by the new rules that pervasive Internet access made possible.

While cheap Internet was a necessary condition for the Linux model to evolve, I think it was not by itself a sufficient condition. Another vital factor was the development of a leadership style and set of cooperative customs that could allow developers to attract co-developers and get maximum leverage out of the medium.

But what is this leadership style and what are these customs? They cannot be based on power relationships—and even if they could be, leadership by coercion would not produce the results we see. Weinberg quotes the autobiography of the 19th-century Russian anarchist Pyotr Alexeyvich Kropotkin's *Memoirs of a Revolutionist* to good effect on this subject:

Having been brought up in a serf-owner's family, I entered active life, like all young men of my time, with a great deal of confidence in the necessity of commanding, ordering, scolding, punishing and the like. But when, at an early stage, I had to manage serious enterprises and to deal with [free] men, and when each mistake would lead at once to heavy consequences, I began to appreciate the difference between acting on the principle of command and discipline and acting on the principle of common understanding. The former works admirably in a military parade, but it is worth nothing where real life is concerned, and the aim can be achieved only through the severe effort of many converging wills.

The ``severe effort of many converging wills'' is precisely what a project like Linux requires—and the ``principle of command'' is effectively impossible to apply among volunteers in the anarchist's paradise we call the Internet. To operate and compete effectively, hackers who want to lead collaborative projects have to learn how to recruit and energize effective communities of interest in the mode vaguely suggested by Kropotkin's ``principle of understanding''. They must learn to use Linus's Law.[SP]

Earlier I referred to the ``Delphi effect'' as a possible explanation for Linus's Law. But more powerful analogies to adaptive systems in biology and economics also irresistably suggest themselves. The Linux world behaves in many respects like a free market or an ecology, a collection of selfish agents attempting to maximize utility which in the process produces a self-correcting spontaneous order more elaborate and efficient than any amount of central planning could have achieved. Here, then, is the place to seek the ``principle of understanding''.

The ``utility function'' Linux hackers are maximizing is not classically economic, but is the intangible of their own ego satisfaction and reputation among other hackers. (One may call their motivation ``altruistic'', but this ignores the fact that altruism is itself a form of ego satisfaction for the altruist). Voluntary cultures that work this way are not actually uncommon; one other in which I have long participated is science fiction fandom, which unlike hackerdom has long explicitly recognized ``egoboo'' (ego-boosting, or the enhancement of one's reputation among other fans) as the basic drive behind volunteer activity.

Linus, by successfully positioning himself as the gatekeeper of a project in which the development is mostly done by others, and nurturing interest in the project until it became self-sustaining, has shown an

acute grasp of Kropotkin's ``principle of shared understanding''. This quasi-economic view of the Linux world enables us to see how that understanding is applied.

We may view Linus's method as a way to create an efficient market in ``egoboo''—to connect the selfishness of individual hackers as firmly as possible to difficult ends that can only be achieved by sustained cooperation. With the fetchmail project I have shown (albeit on a smaller scale) that his methods can be duplicated with good results. Perhaps I have even done it a bit more consciously and systematically than he.

Many people (especially those who politically distrust free markets) would expect a culture of self-directed egoists to be fragmented, territorial, wasteful, secretive, and hostile. But this expectation is clearly falsified by (to give just one example) the stunning variety, quality, and depth of Linux documentation. It is a hallowed given that programmers *hate* documenting; how is it, then, that Linux hackers generate so much documentation? Evidently Linux's free market in egoboo works better to produce virtuous, other-directed behavior than the massively-funded documentation shops of commercial software producers.

Both the fetchmail and Linux kernel projects show that by properly rewarding the egos of many other hackers, a strong developer/coordinator can use the Internet to capture the benefits of having lots of co-developers without having a project collapse into a chaotic mess. So to Brooks's Law I counter-propose the following:

> 19: Provided the development coordinator has a communications medium at least as good as the Internet, and knows how to lead without coercion, many heads are inevitably better than one.

I think the future of open-source software will increasingly belong to people who know how to play Linus's game, people who leave behind the cathedral and embrace the bazaar. This is not to say that individual vision and brilliance will no longer matter; rather, I think that the cutting edge of open-source software will belong to people who start from individual vision and brilliance, then amplify it through the effective construction of voluntary communities of interest.

Perhaps this is not only the future of *open-source* software. No closed-source developer can match the pool of talent the Linux community can bring to bear on a problem. Very few could afford even to hire the more than 200 (1999: 600, 2000: 800) people who have contributed to fetchmail!

Perhaps in the end the open-source culture will triumph not because cooperation is morally right or software ``hoarding'' is morally wrong (assuming you believe the latter, which neither Linus nor I do), but simply because the closed-source world cannot win an evolutionary arms race with open-source communities that can put orders of magnitude more skilled time into a problem.