Some thoughts on security after ten years of qmail 1.0

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“Every few months CERT announces Yet Another Security Hole In Sendmail—something that lets local or even remote users take complete control of the machine. I’m sure there are many more holes waiting to be discovered; Sendmail’s design means that any minor bug in 41000 lines of code is a major security risk. Other popular mailers, such as Smail, and even mailing-list managers, such as Majordomo, seem just as bad.”
Solution: Write a secure MTA!

1995.12.07 version of qmail:
   14903 words of code.

1996.01.21, 0.70:     74745 words.
1996.08.01, 0.90:     105044 words.
1997.02.20, 1.00:     117685 words.
1998.06.15, 1.03:     124540 words.
netqmail 1.05:         124911 words.

Total known bugs in the
qmail 1.0 releases: 4.
Total known security holes: 0.
Compare to Sendmail:

1996.03, 8.7.5: 178375 words.
1997.01, 8.8.5: 209955 words.
1998.05, 8.9.0: 232188 words.

Hundreds of known bugs; many security holes.

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But, in each MTA, most code focuses on core MTA features.
Why the complexity gap?


More than 1 million of the Internet’s SMTP servers run qmail today.

2007.11: $500 → $1000; qmail placed into public domain.
Mission: Invulnerable

Most “security” mechanisms are breakable, and are broken as soon as they become popular.

The conventional wisdom:
“We’ll never build a serious software system without security holes.”

Why not? “It’s impossible.”
Or: “Maybe it’s possible, but it’s much too expensive.”
The conventional wisdom: “We’ll never build a tunnel from England to France.”

Why not? “It’s impossible.”
Or: “Maybe it’s possible, but it’s much too expensive.”

Engineer’s reaction:
How expensive is it?
How big a tunnel *can* we build?
How can we reduce the costs?
Eliminating bugs

Estimate bug rate of software-engineering processes by carefully reviewing code. (Estimate is reliable enough; “all bugs are shallow.”)

Meta-engineer processes that have lower bug rates. Note: progress is quantified.

Well-known example: Drastically reduce bug rate of typical engineering process by adding coverage tests.
Example where qmail did well: “Don’t parse.”


qmail’s internal file structures and program-level interfaces don’t have exceptional cases. Simplest code is correct code.
Example where qmail did badly: integer arithmetic.

In C et al., \( a + b \) *usually* means exactly what it says, but *occasionally* doesn’t.

To detect these occasions, need to check for overflows. Extra work for programmer.

To guarantee sane semantics, extending integer range and failing only if out of memory, need to use large-integer library. Extra work for programmer.
The closest that qmail has come to a security hole (Guninski): potential overflow of an unchecked counter.

Fortunately, counter growth was limited by memory and thus by configuration, but this was pure luck.

Anti-bug meta-engineering: Use language where \(a + b\) means exactly what it says.
“Large-integer libraries are slow!”

That’s a silly objection. We need invulnerable systems, and we need them today, even if they are $10\times$ slower than our current systems. Tomorrow we’ll make them faster.

Most CPU time is consumed by a very small portion of all the system’s code. Most large-integer overheads are removed by smart compilers. Occasional exceptions can be handled manually at low cost.
Paper has more examples of anti-bug meta-engineering: automatic array extensions; partitioning variables to make data flow visible; automatic updates of “summary” variables; abstraction for testability.

“Okay, we can achieve much smaller bug rates. But in a large system we’ll still have many bugs, including many security holes!”
Eliminating code

Measure code rate of software-engineering processes.

Meta-engineer processes that spend less code to get the same job done.
Note: progress is quantified.

This is another classic topic of software-engineering research. Combines reasonably well with reducing bug rate.
Example where qmail did well: reusing access-control code.

A story from twenty years ago: My `.forward` ran a program creating a new file in `/tmp`. Surprise: the program was sometimes run under another uid!

How Sendmail handles `.forward`:
Check whether user can read it. (Prohibit symlinks to secrets!)
Extract delivery instructions.
Keep track (often via queue file) of instructions and user.

Many disastrous bugs here.
OS already tracks users.
OS already checks readability.
Why not reuse this code?

How qmail delivers to a user:
Start qmail-local under the right uid.

When qmail-local reads the user’s delivery instructions, the OS checks readability.
When qmail-local runs a program, the OS assigns the same uid to that program.
No extra code required!
Example where qmail did badly: exception handling.

qmail has thousands of conditional branches. About half are simply checking for temporary errors.

Easy to get wrong: e.g., “if ipme_init() returned -1, qmail-remote would continue” (fixed in qmail 0.92).

Easily fixed by better language.
Paper has more examples of small-code meta-engineering: identifying common functions; reusing network tools; reusing the filesystem.

“Okay, we can build a system with less code, and write code with fewer bugs. But in a large system we’ll still have bugs, including security holes!”
Eliminating trusted code

Can architect computer systems to place most of the code into untrusted prisons.

Definition of “untrusted”: no matter what the code does, no matter how badly it behaves, no matter how many bugs it has, it cannot violate the user’s security requirements.

Measure trusted code volume, and meta-engineer processes that reduce this volume.

Note: progress is quantified.
Warning: “Minimizing privilege” rarely eliminates trusted code.

Every security mechanism, no matter how pointless, says it’s “minimizing privilege.” This is not a useful concept.

qmail did very badly here. Almost all qmail code is trusted. I spent considerable effort “minimizing privilege”; stupid! This distracted me from eliminating trusted code.
Example: `jpegtopnm`, converting JPEG into bitmap.

Easy to run `jpegtopnm` in an “extreme sandbox” that allows nothing but (1) reading the JPEG file, (2) writing the bitmap, and (3) allocating limited memory. Then `jpegtopnm` is untrusted.

Oops: cache-timing attacks etc. violate memory “protection.” Solution: restrict CPU access, for example with an interpreter.
Warning: Trusted code is much more than the kernel.

(Orange Book screwed up: defined TCB much too narrowly, confusing many people. Lampson/Abadi/Burrows/Wobber give correct definition.)

Web-browser code is trusted. But replace web browser’s built-in JPEG decompression by a sandboxed jpegtopnm and then that code is untrusted. Can replace many components.
Analogy:
Give someone an account. Allow him to upload a JPEG, log in, run jpegtopnm, show you the final bitmap.

The upload and jpegtopnm can’t touch your files!

Same for every transformation that handles single-source data. This is a huge amount of code. We can make all of it untrusted.
What code remains trusted? What types of code handle data from multiple sources?

One common pattern: merge data into “summary”; then transform the summary.

Example: merge mail messages into a list of subjects. Transformations of list are then trusted.

Usually can delay the merge, transforming messages separately. Transform is then single-source.
Always have some trusted code.

Have to identify data sources (local users, URLs, etc.); copy this identification from inputs to outputs; cryptographically protect network connections; etc.

But I see no reason that trusted code has to be a large fraction of all code on the computer system.
The future

Architect systems so that most functions are untrusted. Minimize volume of code providing those functions. Minimize bug rate in that code.

My prediction: We will have invulnerable software systems, with no bugs in trusted code. We will be confident that these systems enforce the user’s security requirements.