A Boss's Guide to Software Process Improvement

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I hear from plenty of readers that their bosses just don't "get" software. Efforts to institute even limited methods to produce better code are thwarted by well-meaning but uninformed managers chanting the "can't you just write more code?" mantra.

Yet when I talk to the bosses many admit they simply don't know the rules of the game. Software engineering isn't like building widgets or designing circuit boards. The disciplines are quite different, techniques and tools vary, and the people themselves all too often quirky and resistant to standard management ploys. Most haven't the time or patience to study dry tomes or keep up with the standard journals. So here's my short-intro to the subject. Give it to your boss.

Dear boss: the first message is one you already know. Firmware is the most expensive thing in the universe. Building embedded code will burn through your engineering budget at a rate matched only by a young gold-digger enjoying her barely-sentient ancient billionaire's fortune.

Most commercial firmware costs around $15 to $30 per line, measured from the start of a project till it's shipped. When developers tell you they can "code that puppy over the weekend" be very afraid. When they estimate $5/line, they're on drugs or not thinking clearly. Defense work with its attendant reams of documentation might run upwards of $100 per line or more; the space shuttle code is closer to $1000 per line, but is without a doubt the best code ever written.

$15-$30 per line translates into a six figure budget for even a tiny 5k line application. The moral: embarking on any development endeavor without a clear strategy is a sure path to squandering vast sums.

Like the company that asked me to evaluate a project that was 5 years late and looked more hopeless every day. I recommended they trash the $40m effort and start over, which they did. Or the startup which, despite my best efforts to convince them otherwise, believed the consultants' insanely optimistic schedule. They're now out of business - the startup, that is. The consultants are thriving.

Version Control

First, before even thinking about building any sort of software, install and have your people use a version control system (VCS). Building even the smallest project without a VCS is a waste of time and an exercise in futility.

The NEAR spacecraft dumped a great deal of its fuel and was nearly lost when an accelerometer transient caused the on-board firmware to execute abort code… incorrect abort code, software that had never really been tested. Two versions of the 1.11 flight software existed; unhappily, the wrong set flew. The code was maintained on uncontrolled servers. Anyone could, and did, change the software. Without adequate version control, it wasn't clear what made up correct shipping software.

A properly deployed VCS insures these sorts of dumb mistakes just don't happen. The VCS is a sort of database for software, releasing the code to users but tracking who changed what when. Why did the latest set of changes break working code? The VCS will report what changed, who did it, and when, giving the team a chance to efficiently troubleshoot things.

Maybe you're shipping release 2.34, but one user desperately requires the old 2.1 software. Perhaps a bug snuck in sometime in the last 10 versions and you need to know which code is safe. A VCS reconstructs any version at any time.

Have you ever misplaced code? In October of 1999 the FAA announced they had lost the source code to all of the software that controlled air traffic between Chicago and the regional airports. The code all lived on one developer's machine, one angry person who quit and deleted it all. He did, however, install it on his home computer, encrypted. The FBI spent 6 months reverse engineering the encryption key to get their code back. Sound like disciplined software development? Maybe not.

Without a VCS, a failure of any engineer's computer will mean you lose code, since it's all inevitably scattered around amongst the development team. Theft or a fire – unhappily everyday occurrences in the real world – might bankrupt you. The computers have little value, but that source code is worth millions.

The version control database – the central repository of all of your valuable software – lives on a single server. Daily backups of that machine, stored offsite, insures your business's survival despite almost any calamity.

Some developers complain that the VCS won't protect them from lazy programmers who cheat the system. You or your team lead should audit the VCS's logs occasionally to be sure developers aren't checking out modules and leaving them on their own computers. A report that takes just seconds to produce will tell you who hasn't checked in code, and how long it has been out on their own computers.

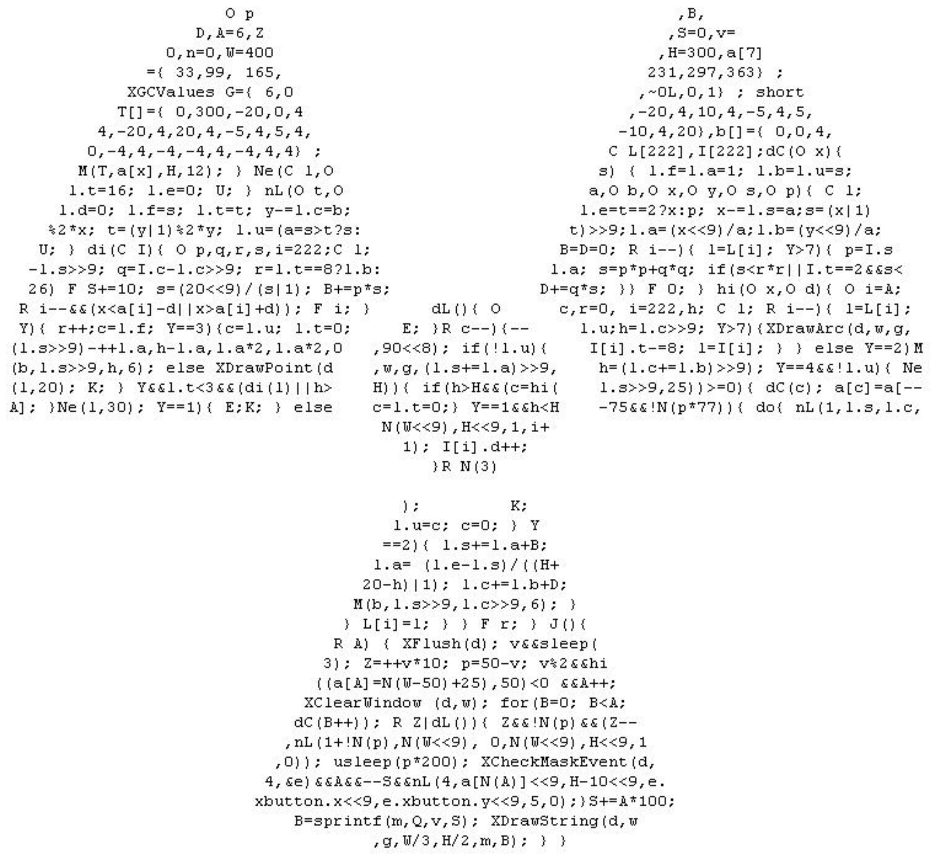
Version control systems range in price from free (like the GNU products) to expensive, but even the expensive ones are cheap. See http://better-scm.berlios.de/comparison/comparison.html
for a comprehensive list of products.

Firmware Standards

What language is spoken in America? English, of course, but try talking to random strangers on a street corner in Baltimore today. The dialects range from educated middle-American to incomprehensible near-gibberish. It's all English, of a sort, but it sounds more like the fallout from the Tower of Babel.

In the firmware world we speak a common language: C, C++ or assembly, usually. Yet there's no common dialect; developers exploit different aspects of the lingos, or construct their programs using legal but confusing constructs.

The purpose of software is to work, of course, but also to clearly communicate the programmer's intentions to maintenance people. Clear communications means we must all use similar dialects. Someone – that's you, boss – must specify the dialect.



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                      O p                                            ,B,
                   D,A=6,Z                                          ,S=0,v=
                0,n=0,W=400                                        ,H=300,a[7]
              ={ 33,99, 165,                                      231,297,363} ;
            XGCValues G={ 6,0                                    ,~0L,0,1} ; short
           T[]={ 0,300,-20,0,4                                  ,-20,4,10,4,-5,4,5,
         4,-20,4,20,4,-5,4,5,4,                                -10,4,20},b[]={ 0,0,4,
        0,-4,4,-4,-4,4,-4,4,4} ;                              C L[222],I[222];dC(O x){
       M(T,a[x],H,12); } Ne(C l,O                            s) { l.f=l.a=1; l.b=l.u=s;
      l.t=16; l.e=0; U; } nL(O t,O                          a,O b,O x,O y,O s,O p){ C l;
     l.d=0; l.f=s; l.t=t; y-=l.c=b;                        l.e=t==2?x:p; x-=l.s=a;s=(x|1)
    %2*x; t=(y|1)%2*y; l.u=(a=s>t?s:                      t)>>9;l.a=(x<<9)/a;l.b=(y<<9)/a;
   U; } di(C I){ O p,q,r,s,i=222;C l;                    B=D=0; R i--){ l=L[i]; Y>7){ p=I.s
  -l.s>>9; q=I.c-l.c>>9; r=l.t==8?l.b:                  l.a; s=p*p+q*q; if(s<r*r||I.t==2&&s<
  26) F S+=10; s=(20<<9)/(s|1); B+=p*s;                D+=q*s; }} F 0; } hi(O x,O d){ O i=A;
 R i--&&(x<a[i]-d||x>a[i]+d)); F i; }       dL(){ O      c,r=0, i=222,h; C l; R i--){ l=L[i];
 Y){ r++;c=l.f; Y==3){c=l.u; l.t=0;      E; }R c--){--     l.u;h=l.c>>9; Y>7){XDrawArc(d,w,g,
(l.s>>9)-++l.a,h-l.a,l.a*2,l.a*2,0    ,90<<8); if(!l.u){    I[i].t-=8; l=I[i]; } } else Y==2)M
(b,l.s>>9,h,6); else XDrawPoint(d     ,w,g,(l.s+=l.a)>>9,    h=(l.c+=l.b)>>9); Y==4&&!l.u){ Ne
(l,20); K; } Y&&l.t<3&&(di(l)||h>     H)){ if(h>H&&(c=hi(    l.s>>9,25))>=0){ dC(c); a[c]=a[--
A]; }Ne(l,30); Y==1){ E;K; } else     c=l.t=0;} Y==1&&h<H    -75&&!N(p*77)){ do{ nL(1,l.s,l.c,
                                       N(W<<9),H<<9,1,i+
                                         1); I[i].d++;
                                            }R N(3)

                                         );          K;
                                        l.u=c; c=0; } Y
                                       ==2){ l.s+=l.a+B;
                                      l.a= (l.e-l.s)/((H+
                                     20-h)|1); l.c+=l.b+D;
                                    M(b,l.s>>9,l.c>>9,6); }
                                   } L[i]=l; } } F r; } J(){
                                  R A) { XFlush(d); v&&sleep(
                                 3); Z=++v*10; p=50-v; v%2&&hi
                                ((a[A]=N(W-50)+25),50)<0 &&A++;
                               XClearWindow (d,w); for(B=0; B<A;
                              dC(B++)); R Z|dL()){ Z&&!N(p)&&(Z--
                             ,nL(1+!N(p),N(W<<9), 0,N(W<<9),H<<9,1
                            ,0)); usleep(p*200); XCheckMaskEvent(d,
                          4,&e)&&A&&--S&&nL(4,a[N(A)]<<9,H-10<<9,e.
                         xbutton.x<<9,e.xbutton.y<<9,5,0);}S+=A*100;
                              B=sprintf(m,Q,v,S); XDrawString(d,w
                                      ,g,W/3,H/2,m,B); } }
```

Figure 1: Real C code… but what dialect? Who can understand this?

The C and C++ languages are so conducive to abuse that there's a yearly obfuscated C contest whose goal is to produce utterly obscure but working code. Figure 1 is an excerpt from one wining entry; this is real, working, but utterly incomprehensible code. Everyone wants the URL to see other bizarre entries, but forget it! These people are code terrorists who should be hunted down and shot like the animals they are! Vow that your group will produce world-class software that's cheap to maintain.

The code won't be readable unless we use constructs that don't cause our eyes to trip and stumble over unusual indentation, brace placement and the like. That means setting rules, a standard, used to guide the creation of all new code.

The standard defines far more than stylistic issues. Deeply nested conditionals, for instance, lead to far more many testing permutations than any normal person can manage. So the standard limits nesting. It specifies naming conventions for variables, promoting identifiers that have real meaning. Tired of seeing i, ii, and (my personal favorite) iii for loop variable names? The standard outlaws such lazy practices. Rules define how to construct useful comments. Comments are an integral and essential part of the source code, every bit as important as for and while loops. Replace or retrain any team member who claims to write "self commenting code."

Some developers use the excuse that it's too time consuming to produce a standard. Plenty exist on the net; mine is in Word doc format at www.ganssle.com/misc/fsm.doc. It contains the brace placement rule that infuriates the most people… so you'll change it and make it your own.

So write or get a firmware standard. And boss, please work with your folks to make sure *all* new code follows the standard.

Code Inspections

What's the cheapest way to get rid of bugs? Why, just don't put any in!

Trite, perhaps, yet there's more than a grain of wisdom there. Too many developers crank lots of code fast, and then spend ages fixing their mistakes. The average project eats 50% of the schedule in debugging and test! Reduce debugging, by inserting fewer bugs, and accelerate the schedule.

Inspect all new code. That is, use a formal process that puts every function in front of a group of developers before they spend any time debugging. The best inspections use a team of about 4 people who examine every line of C in detail. They'll find most of the bugs before testing.

Study after study shows inspections are 20 times cheaper at eliminating bugs than debugging. Maybe you're suspicious of the numbers – fine, divide by an order of magnitude. Inspections still shine, cutting debugging in half.

More compellingly it turns out that most debugging strategies never check half the code. Things like deeply-nested IF statements and exception handlers are tough to test. My collection of embedded disasters shows a similar disturbing pattern: most stem from poorly executed, pretty much untested error handlers.

Inspections and firmware standards go hand in hand. Neither works without the other. The inspections insure programmers code to the standard, and the standard eliminates inspection-time arguments over stylistic issues. If the code meets the standard, then no debates about software styles are permitted.

Most developers hate inspections. Tough. You'll hear complaints that they take too long. Wrong. Well-paced inspection meetings examine 150 lines of code per hour, a rate that's hardly difficult to maintain (that's 2.5 lines of C per minute), yet that costs the company only a buck or so per line. Assuming, of course, that the inspection has no value at all, which we know is simply not true.

Your role, boss, is to grease the skids so the team efficiently cranks out fabulous software. Inspections are a vital part of that process. They won't replace debugging, but will find most of the bugs very cheaply.

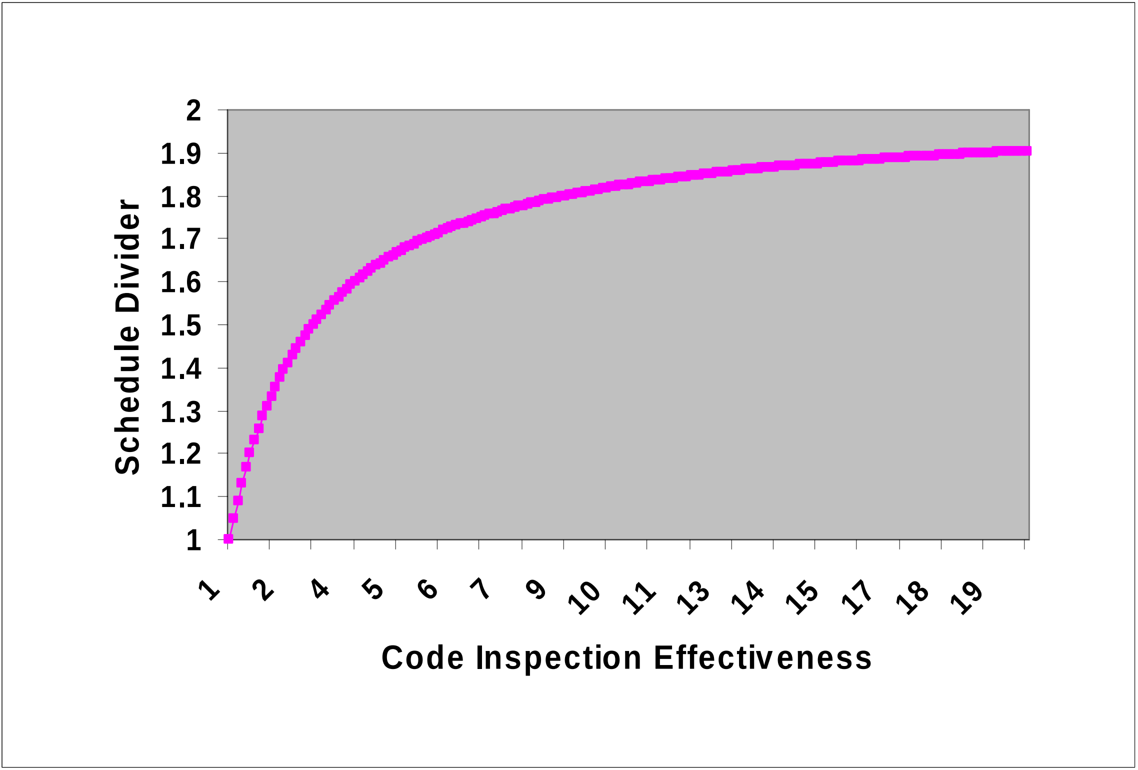

Figure 2: Shaving the schedule with code inspections.

Originally I said code inspections are 20 times cheaper than debugging. That's quite a claim! Figure 2 shows how that at 20x, given that debugging typically consumes half the schedule, using inspections effectively lets you divide the schedule by 1.9.

Don't believe the 20x factor? Divide it by an order of magnitude. Figure 2 shows even at that pessimistic figure you can divide the schedule by 1.3.

Have your people look into inspections closely. The classic reference is *Software Inspection* by Gilb and Graham (Addison-Wesley, NY NY; 1993, ISBN 0201631814), but Karl Wiegers' newer and much more readable book *Peer Reviews in Software* (Addison-Wesley, NY NY, 2001, ISBN 0-201-73485-0) targets teams of all sizes (including solo programmers).

Chuck Crap

Toss out bad code.

A little bit of the software is responsible for most of the debugging headaches. When your developers are afraid to make the smallest change to a module, that's a sure sign it's time to rewrite the offending code.

Developers tend to accept their mistakes, to attempt to beat lousy code into submission. It's a waste of time and energy. Barry Boehm showed in *Software Engineering Economics* that the crummy modules consume 4 times the development effort of any other module.

Identify bad sections early, before wasting too much time on them, and then recode. Count bug rates using bug tracking software. Histogram the numbers occasionally to find those functions whose error rates scream "fix me!"… and have the team recode.

Figure on tossing out about 5% of the system. Remember that Boehm showed this is much cheaper than trying to fix it.

Don't beat your folks up for the occasional function that's a bloody mess. They may have screwed up, but have learned a lot about what should have been done. Use the experience as a chance to create a killer implementation of the function, now that the issues are clearly understood. Healthy teams use mistakes as learning experiences.

Use bug tracking software, such as the free bugzilla (http://www.bugzilla.org/), or any of dozens of commercial products (nice list at http://www.aptest.com/resources.html).

Even the most disciplined developers sometimes do horrible things in the last few weeks to get the device out the door. Though no one condones these actions, fact is that quick hacks happen in the mad rush to ship. That's life. It's also death for software.

Quick hacks tend to accumulate. Version 1.0 is pretty clean, but the evil inflicted in the last few weeks of the project add to problems induced in 1.1, multiplied by an ever-increasing series of hacks added to every release. Pretty soon the programming team says things like "we can't maintain this junk anymore." Then it's too late to take corrective action.

Acknowledge that some horrible things happened in the shipping mania. But before adding features or fixing bugs in the next release, give the developers time to clean up the mess. Pay back the technical debt they incurred in the previous version's end game. Otherwise these hacks will haunt the system forever, reduce overall productivity as the team struggles with the lousy code in each maintenance cycle, and eventually cause the code to rot to the point of uselessness.

Tools

A poll on embedded.com (http://embedded.com/pollArchive/?surveyno=12900001) suggests 85% of companies won't spend more than $1k on any but the most essential tools. Considering the $100k+ loaded cost of a single engineer, it's nuts to not spend a few grand on a tool that offers even a small productivity boost.

Like what? Lint, for one. Lint is a program that examines the source code and identifies suspicious areas. It's like the compiler's syntax checker, but one on steroids. Only Lint is smart enough to watch variable and function usage across multiple files. Compilers can't do that. Aggressive Lint usage picks out many problems before debugging starts, for a fraction of the cost. Lint all source files before doing code inspections.

Gimpel (www.gimpel.com) sells one for $239. It's up to you to buy it, and to insure your engineers use it on all new code. Lint is annoying at first, often initially zeroing in on constructs that are indeed fine. Don't let that quirk turn your people off. Tame it, and then reap great reductions in debugging times.

Debugging eats 50% of most projects' schedules. The average developer has a 5 to 10% error rate. Anything that trims that even a smidgen saves big bucks.

Make sure the developers aren't cheating their tools. Warning levels on compilers, for instance, should be set to the lowest possible level so all warnings are displayed. And then insist the team writes warning-free code. It's astonishing how we ship firmware that spews warnings when compiled. The compiler, which understands the language's syntax far better than any of your people, is in effect shouting "Look here. Here! This is scary!" How can anyone ignore such a compelling danger sign?

Write warning-free code so that maintenance people in months or decades won't be baffled by the messages. "Is it supposed to do this? Or did I reinstall the compiler incorrectly? Which of these is important?" This means changing the way they write C. Use explicit casting. Parenthesis when there's any doubt. These are all good programming practices anyway, with zero cost in engineering, execution speed, or code size. What's the downside?

Editors, compilers, linkers, and debuggers are essential and non-negotiable tools as it's impossible to do any development without these. Consider others. Complexity analyzers can yield tremendous insight into functions, identifying "bad code" early, before the team wastes their time and spirits trying to beat the cruddy code into submission. See www.chris-lott.org/resources/cmetrics/ for a list of freebies. Bug tracking software helps identify problem areas – see a list of resources at http://www.aptest.com/resources.html.

Most firmware developers are desperate for better debugging tools. Unhappily, the grand old days of in-circuit emulators are over. These tools provided deep insight into the intrinsically hard-to-probe embedded system. Their replacement, the BDM, offers far less capability. Have mercy on your folks and insist the hardware team dedicate a couple of spare parallel output bits just to the software people. They'll use these along with instrumented code for a myriad of debugging tasks, especially for hard-to-measure performance issues.

Peopleware

Your developers – not tools, not widgets, not components - are your prime resource. As one wag noted, "my inventory walks out the door each night."

I've recommended several books. Please, though, read *Peopleware* by DeMarco and Lister (ISBN 0932633439, 1999 Dorset House Publishing, NY NY). It's a slender volume that you'll plow through in just a couple of enjoyable hours. Pursuing the elusive underpinnings of software productivity, for 10 years the authors conducted a "coding war" between volunteering companies.

The results? Well, at first the data was a scrambled mess. Nothing correlated. Teams that excelled on the projects (by any measure: speed, bug count, matching specs) were neither more highly paid nor more experienced than the losers. Crunching every parameter revealed the answer: developers imprisoned in noisy cubicles, those who had no defense against frequent interruptions, did poorly.

How poorly? The numbers are breathtaking. The best quartile was 300% more productive than the lowest 25%. Yet privacy was the only difference between the groups.

Think about it – would you like 3x faster development?

It takes your developers 15 minutes, on average, to move from active perception of the office busyness to being totally and productively engaged in the cyberworld of coding. Yet a mere 11 minutes passes between interruptions for the average developer. Ever wonder why firmware costs so much? Email, the phone, people looking for coffee filters and sometimes you, boss, all clamor for attention

Sadly, most developers live in cubicles today, which are, as Dilbert so astutely noted, "anti-productivity pods." Next time you hire someone peer into his cube occasionally. At first he's anxious to work hard, focus, and crank out a great product. He'll try to tune out the poor sod in the next cube who's jabbering on the phone with his lawyer about the divorce. But we're all human; after a week or so he's leaning back from the keyboard, ears raised to get the latest developments. A productive environment? Nope.

I advise you to put your developers in private offices, with doors and off-switches on the phones. You probably won't do that. Every time I've fought this battle with management I've lost, usually because the interior designers promise cubes offer more "flexibility." But even cubicles have options.

Encourage your people to identify their most productive hours, that time of day when their brains are engaged and working at max efficiency. Me, I'm a morning person. Others have different habits. But find those productive hours and help them shield themselves from interruptions for about three hours a day. In that short time, with the 3x productivity boost, they'll get an entire day's work done. The other five hours can be used for meetings, email, phone contacts, supporting other projects, etc.

Give your folks a curtain to pull across the cube's opening. Obviously a curtain rod would decapitate employees, generally a bad idea despite the legions of unemployed engineers clamoring for work. Use a Velcro strip to secure the curtain in place. Put a sign on the curtain labeled "enter and die;" the sign and curtain go up during the employee's 3 superprogramming hours per day. Train the team to respect their colleagues' privacy during these quiet hours. At first they'll be frantic: "but I've GOT to know the input parameters to this function or I'm stuck!" With time they'll learn when Joe, Mary or Bob will be busy and plan ahead. Similarly, if *you* really need a project update and Shirley has her curtain up, back slowly and quietly away. Wait till their hours of silence are over.

Have them turn off their phone during this time. If Mary's spouse needs her to pick up milk on the way home, well, that's perfect voicemail fodder. If the kids are in the hospital, then the phone attendant can break in on her quiet time.

The study took place before email was common. You know, that cute little bleep that alerts you to the same tired old joke that's been circulating around the 'net for the last three months… while diverting attention from the problem at hand. Every few seconds, it seems. Tell your people to disable email while cloistered.

When I talk to developers about the interruption curse they complain that the boss is the worst offender. Resist the temptation to interrupt. Remember just how productive that person is at the moment, and wait till the curtain comes down.

(If you're afraid the employee is hiding behind the curtain surfing the net or playing Doom, well, there are far more severe problems than just productivity issues. Without trust – mutual trust – any engineering department is in trouble).

Other Tidbits

Where should you use your best people? It's natural to put the superprogrammers on the biggest and most complex projects. Resist that urge – it's wrong.

Capers Jones showed that the best people excel on small (one man-month) projects, typically being 6 times more productive than the worst members of the team. That advantage diminishes as the system grows. On an 8 man-month effort the ratio shrinks to under 3 to 1. At 64 man-months it's about 1.5 to 1, and much beyond that the best do as badly as the worst. Or the worst as well as the best. Whatever.

That observation tells us something important about how we partition big projects. Find ways to break big systems down into many small, mostly independent parts. Or at least strip out as much as possible from the huge carcass of code you're planning to generate, putting the removed sections into their own tasks or even separate processors. Give these smaller sections to the superprogrammers. They'll crank out solutions fast.

An example: suppose an I/O device, say an optical encoder, is tied to your system. Remove it. Add a CPU, a cheap PIC, ATMEL, Z8 or similar sub-$1 part, just to manage that one device. Have it return its data in engineering units: "the shaft angle is 27 degrees." Even a slowly rotating encoder would generate thousands of interrupts a second, a burden to even the fastest CPU that's also tasked with a many other activities. Yet even a tiny microcontroller can easily handle the data if there's nothing else going on. One smart developer can crank out perfect I/O code in little time.

(An important rule of thumb states that 90% loaded systems double development time, compared to one of 70% or less; 95% loading triples development time.)

While cleverly partitioning the project for the sake of accelerating the development schedule, think like the customer does, not as the firmware folks do. The customer only sees features; never objects, ISRs or functions. Features are what sell the product.

That means break the development effort down into feature-chunks. The first feature of all, of course, is a simple skeleton that sets up the peripherals and gets to main(). That and a few critical ISRs, perhaps an RTOS and the like form the backbone upon which everything else is built.

Beyond the backbone are the things the customer will see. In a digital camera there's a handler for the CCD, an LCD subsystem, some sort of Flash filesystem. Cool tricks like image enhancement, digital zoom, and much more will be the sizzle that excites marketing. None of those, of course, has much to do with the basic camera functionality.

Create a list of the features and prioritize. What's most important? Least? Then… and this is the trick… implement the most important features first.

Does that sound trite? It is, yet every time I look at a product in trouble no one has taken this step. Developers have virtually every feature half-implemented. The ship date arrives and nothing works. Worse, there's no clear recovery strategy since so much effort has been expended on things that are not terribly important.

So in a panic management starts tossing out features. One 2002 study showed that 74% of projects wind up with 30% or more of the features being eliminated. Not only is that a terrible waste – these are partially implemented features – but the product goes to market late, with a subset of its functionality. If the system were built as I'm recommending, even schedule slippages would, at worst, result in scrubbing a few requirements that had as yet not consumed engineering time. Failure, sure, but failure in a rather successful way.

Finally, did you know great code, the really good stuff, that which has the highest reliability, costs the same as cruddy software? This goes against common sense. Of course, all things being equal, highly safety critical code is much more expensive that consumer-quality junk.

But what if we don't hold all things equal? O. Benediktsson (*Safety Critical Software and Development Productivity,* conference proceedings, Second World Conference on Software Quality, Sept 2000) showed that using higher and higher levels of disciplined software process lets one build higher-rel software at a constant cost. If your projects march from low reliability along an upwards line to truly safety-critical code, and if your outfit follows, in his study, increasing levels of the Capability Maturity Model, the cost remains constant.

Makes one think. And hopefully, it makes one reign in the hackers who are more focused on cranking code than specifying, designing, and carefully implementing a world-class product.