Secure Programming Lecture 9: Secure Development

David Aspinall

Informatics Edinburgh

Outline

Recap

We've looked in detail at important **vulnerability classes**:

- overflows, stack and heap
- injections, command and SQL
- race conditions

We've seen **secure development processes** from the outside:

- vulnerability advisories, CVE classifications
- maturity model for secure software dev't: BSIMM

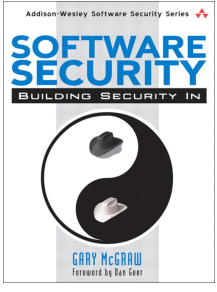
It's time to delve a bit more into **secure development activities** included in BSIMM.

A *Building Security In* Process

We'll look at a:

Secure Software Development Lifecycle (SSDLC)

due to **Gary McGraw** and described in his 2006 book *Software Security: Building Security In*.



A *Building Security In* Process

Work by McGraw and others has been combined in the best practices called **Building Security In**.

It is used in the BSIMM survey mentioned earlier:

- BSIMM is proposed as a *Maturity Model* for real-world best practices in software-producing companies

This has been promoted by the US-CERT and in Carnegie Mellon University's Software Engineering Institute:

- Cybersecurity Engineering

Lately there is an emphasis on a broader scope, with CMU/SEI developing a *Software Assurance Framework* which covers more of the application lifecycle, emphasising design flaws and supply chains.

Outline

McGraw's "Three Pillars"

I: Applied Risk Management

Identify, rank, track risks. Threat modelling helps find security risks.

II: Software Security Touchpoints

Seven lifecycle stages for building-in security-related activities.

III: Knowledge

Applying previous or new knowledge, e.g., programming guidelines and rules, or known exploits and attack patterns.

To avoid debates over specific development processes, BSI was based on best practice activities seen in multiple organisations.

Touchpoints: Security activities during development

How should secure development practices be incorporated into traditional software development?

0. treat security separately as a new activity (wrong)
1. invent a new, security-aware process (another fad)
2. **run security activities alongside traditional**

In business, “touchpoints” are places in a product/sales lifecycle where a business connects to its customers.

McGraw adapts this to suggest “touchpoints” in software development where security activities should interact with regular development processes.

Security activities during lifecycle

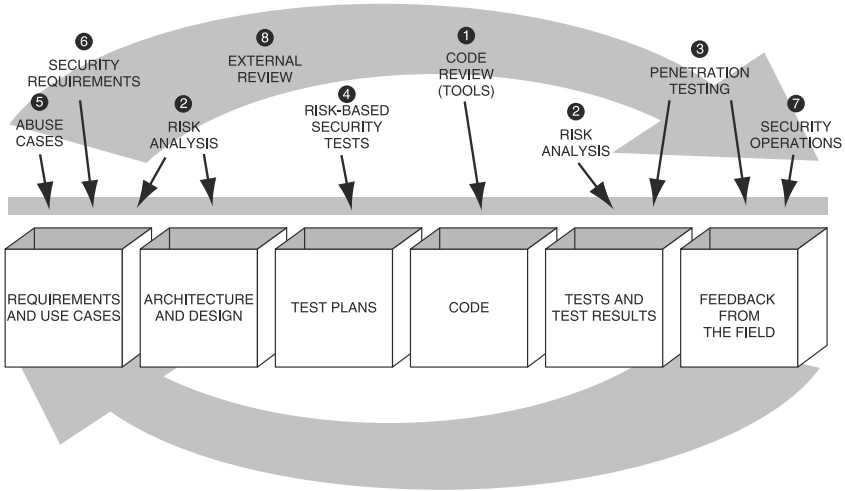
McGraw identified 7 touchpoint activity areas, connecting to software development artefacts. In lifecycle order:

- **Abuse cases** (in requirements)
- **Security requirements** (in requirements)
- **Risk analysis** (in requirements, design, and test)
- **Risk-based security tests** (in test planning)
- **Code review** (in coding)
- **Penetration testing** (in testing and deployment)
- **Security operations** (during deployment)

His process modifies one adopted by Microsoft after the infamous *Trustworthy computing* Gates Memo in 2002.

Exercise. For each touchpoint (detailed shortly), identify the development artefact(s) it concerns.

Touchpoints in the software development lifecycle



The numbers are a ranking in order of effectiveness.

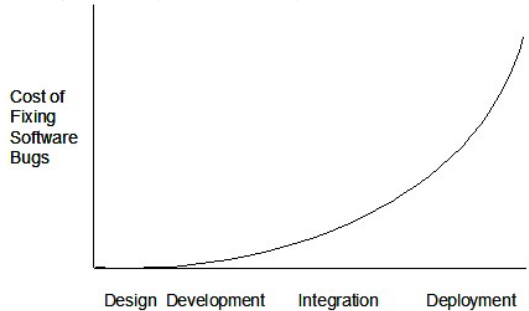
Outline

1. Code review

Most effective touchpoint: eliminate problems at source.

Evidence since 1970s shows bugs are orders of magnitude cheaper to fix during coding than later in the lifecycle.

Code QA processes aren't as widely deployed as you might imagine, but things are perhaps improving. (**Q.** Why?)



Code review types

- **Manual code review**
  - can find subtle, unusual problems
  - an onerous task, especially for large code bases
  - but adopted dev cycle in some agile processes (e.g., Google)
- **Automatic static analysis**
  - increasingly sophisticated tools automate scanning
  - very useful but can never understand code perfectly
  - and may need human configuration, interpretation

Especially effective for simple bugs such as overflows.

Outline

2. Architectural risk analysis

Two kinds of security defects

IMPLEMENTATION BUGS

- Buffer overflow
  - String format
  - On stage attacks
- Race conditions
  - TOCTOU (time of check to time of use)
- Unsafe environment variables
- Unsafe system calls
- Cross-site scripting
- SQL injection

50%

ARCHITECTURAL FLAWS

- Misuse of cryptography
- Compartmentalization problems in design
- Privileged block protection failure (DoPrivilege())
- Catastrophic security failure (fragility)
- Type safety confusion error
- Insecure auditing
- Broken or illogical access control (RBAC over tiers)
- Method over-riding problems (subclass issues)
- Signing too much code

50%

Design flaws

Design flaws are not obvious from staring at code; they need to be identified in the design phase.

Architectural risk analysis considers risk during requirements, design, and testing:

- the security **threats** that attackers pose to **assets**
- **vulnerabilities** that allow **threats** to be realised
- the **impact** and **probability** of an attack
- hence the **risk**, as risk = probability × impact
- **countermeasures** that may be put into place

Example: poor protection of secret keys; risk is deemed high that attacker can read key stored on the filesystem and then steal encrypted document. A countermeasure is to keep encryption keys on dedicated USB tokens.

Risk analysis in general

- Several approaches:
  - financial loss oriented (cost versus damage)
  - mathematical (or pseudo-mathematical) risk ratings
  - qualitative methods using previous knowledge
- If possible, should use specialist non-developers
  - requires understanding business impact
  - perhaps legal and regulatory framework
  - devs often strongly opinionated, fixed assumptions

The (modern) Board-level view:

- a **Chief Risk Officer** manages risk across organisation
- balance cyber security with other types of risk

Common steps in risk analysis

1. Study system (specs, design docs, code, tests)
2. Identify threats and attackers types/routes
3. List possible vulnerabilities in the software
4. Understand planned security controls (& risks\dots)
5. Map attack scenarios (routes to exploit)
6. Perform impact analysis
7. Using likelihood estimates, **rank risks**
8. Recommend countermeasures in priority/cost order

Particular risk analysis methods refine these.

In steps 2 and 3, may use checklists of threat types and previously known vulnerabilities; also general “goodness” guidelines.

Security design guidelines

Saltzer and Schroeder (1975)'s classic principles are a good example of high-level design guidelines:

1. **Economy of mechanism**: *keep it simple, stupid*
2. **Fail-safe defaults**: *e.g., no single point of failure*
3. **Complete mediation**: *check everything, every time*
4. **Open design**: *assume attackers get the source & spec*
5. **Separation of privilege**: *use multiple conditions*
6. **Least privilege**: *no more privilege than needed*
7. **Least common mechanism**: *beware shared resources*
8. **Psychological acceptability**: *are security ops usable?*

Exercise. If you haven't studied these already, you should review them in detail.

Microsoft STRIDE approach

STRIDE is mnemonic for categories of threats in Microsoft's method:

- **S**poofing: *attacker pretends to be someone else*
- **T**ampering: *attacker alters data or settings*
- **R**epudiation: *user can deny making attack*
- **I**nformation disclosure: *loss of personal info*
- **D**enial of service: *preventing proper site operation*
- **E**levation of privilege: *user gains power of root user*

Exercise. Recall the definitions of the classic CIA security properties (confidentiality, integrity, availability). Explain which properties each threat type attacks.

The STRIDE approach

STRIDE uses *Data Flow Diagrams* to chase data through a system.

- Consider each data flow, manipulation, or storage:
  - Are there vulnerabilities of type S,T,R,I,D,E?
  - Are there routes to attack?
- Design mitigations (countermeasures)

STRIDE was designed as a developer-friendly mechanism

- devs may not know end user's risk tolerance
- so de-emphasises risk assessment, business impact

See MSDN magazine, Nov 2006.

General risk reduction mechanisms

Besides understanding specific threats, we may use general risk-reduction approaches:

- Design to **allow updates**, particularly security patches
- Only use 3rd party components which have been security tested
- Only use approved/vetted up-to-date tools (compilers, IDEs etc.)

Question. Can you think of any other general recommendations to reduce risk?

Question. Are there dangers with general risk reduction approaches?

Outline

3. Penetration testing

Current dominant methodology (alongside bolt-on protection measures, outside the lifecycle). Effective because it considers a program in final environment.

- **Finds real problems**
  - demonstrable exploits easily motivates repair costs
  - process “feels” good: something gets “better”
- **Drawback: no accurate sense of coverage**
  - ready made pen testing tools cover only easy bugs
  - system-specific architecture and controls ignored

Beware Dijkstra’s famous remark: *Testing shows the presence, not the absence of bugs*. Just running some standard pen-testing tools is a very minimal test.

Example: by feeding data to form elements, a browser plugin pen testing tool uncovers XSS vulnerabilities.

Bad use of pen testing

- Pen testing by external consultants is limited
  - they may know tools but not system being tested
  - judgements about code limited (esp if black-box)
- Developers only patch to fix problems they're told about
  - Other patches may not be applied
  - Patches can introduce new problems
  - Patches often only fix symptom, not root cause
- Black box pen testing too limited
  - Modern professional pen testing uses source

Good use of pen testing

McGraw advocates using pen testing:

- At the unit level, earlier in development:
  - automatic fault-injection with *fuzzing* tools
- Before deployment, as a last check
  - not a first check for security, after deployment!
  - risk-based, focus on configuration and environment
- Metrics-driven: tracking problem reduction
  - not imagining zero=perfect security
  - use exploits as regression tests
- For repairing software, not deploying work-arounds

Outline

4. Security testing

Security testing complements QA processes which ensure main functional requirements are error free.

- **Test security functionality**
  - test security functions with standard methods
  - consider them as part of main requirements
  - *write test cases for encryption key update*
- **Test security based on attack patterns or identified abuse cases**
  - apply risk analysis to prioritize
  - consider attack patterns
  - *test for injection vulns in environment vars*

Traditional testing vs security testing

Traditional testing

Testers check a reasonably clear list of desired behaviours.

"The system shall. . . [do X, Y, and Z]"

Explicit functional requirements * check use cases, operate as expected * *customer can add/remove items from cart* **Sometimes explicit** non-functional requirements * check usability, performance * *user experience (UX) is pleasing* * *updating cart takes at most 5 seconds*

Traditional testing vs security testing

Security testing

Testers check an *un*clear list of *un*desirable behaviours are absent.
"The system shall not. . . "

Rarely explicit non-functional *non-requirements* * check undefined, unexpected behaviours impossible * check safe recovery under abnormal conditions * *a negative size input doesn't exhaust memory* * *a web server crash doesn't display debug info*

A strategy for security testing

1. Understand the **attack surface** by enumerating:
   - program inputs
   - environment dependencies: hardware, software, people, ...
2. Use **risk analysis** outputs to prioritize components
   - often highest: code accessed by anonymous, remote users
3. Work through **attack patterns** using fault-injection:
   - use manual input, *fuzzers* or *proxies*
4. Check for **security design errors**
   - privacy of network traffic
   - controls on storage of data, ACLs
   - authentication
   - random number generation

Automating security tests

Just as with functional testing, we can benefit from building up suites of *automated security tests*.

1. Think like an attacker
2. Design test suites to attempt malicious exploits
3. Knowing system, try to violate specifications or assumptions

This goes beyond random *fuzz testing* approaches.

Specially designed **whitebox fuzz testing** is successful at finding security flaws (or, generating exploits).

One approach: use *dynamic test generation*, using symbolic execution to generate inputs that reach error conditions (e.g., buffer overflow).

Outline

5. Abuse cases

Idea: describe the desired behaviour of the system under different kinds of abuse/misuse.

- Work through **attack patterns**, e.g.
  - illegal/oversized input
- Examine **assumptions** made, e.g.
  - interface protects access to plain-text data
  - cookies returned to server as they were sent
- Consider **unexpected events**, e.g.
  - out of memory error, disconnection of server

Specific detail should be filled out as for a use case.

Related idea: **anti-requirements**.

Outline

6. Security requirements

Security needs should be explicitly considered at the requirements stage.

- **Functional security requirements**, e.g.
  - use cryptography to protect sensitive stored data
  - provide an audit trail for all financial transactions
  - only gather essential data (privacy)
- **Emergent security requirements**, e.g.
  - recover on ill-formed input (avoid DoS)
  - minimise side channels (avoid confidentiality leaks)

Outline

7. Security operations

Security during operations means managing the security of the deployed software.

Traditionally this has been the domain of **information security** professionals.

The idea of this touchpoint is to combine expertise of **infosecs** and **devs**.

This has become more critical recently with the rise of **devops**.

Information security professionals

Expert in:

- Incident handling, proactive threat monitoring
- Range and mechanisms of vulnerabilities, cross systems
- Understanding and deploying desirable patches
- Configuring firewalls, IDS, virus detectors, etc

But are rarely *software* experts.

Taking part in the development process can **feed back knowledge from attacks**, or join in **security testing**.

Infosec people understand pentesting from the outside and less from inside. E.g., network security scanners may be more effective than application scanners.

Coders

Expert in:

- Software design, application architecture
- Programming, often single languages
- Build systems, overnight testing

But coders currently may not understand *security in-the-wild*.

Coders focus on the main product, easy to neglect the deployment environment. E.g., VM host environment may be easiest attack vector.

Outline

Summary

This lecture outlined some SSDLC activities.

The descriptions were quite high-level. BSIMM documents over 100 activities used in real-world SSDLCs, organised into 4 domains: **Governance**, **Intelligence**, **Development** and **Deployment**.

Exercise. For each of the touchpoints, find specific documented examples of use in a development process. McGraw's book has some, but there are other sources.

Exercise. Practice thinking about the touchpoints by constructing scenarios. Consider the development of a particular piece of software or a system. Imagine what some of the touchpoints might uncover or recommend.

Review questions

- Describe **5 secure development lifecycle activities** and the points in which they would be used in a compressed 4-stage agile development method (use case, design, code, test).
- What kinds of security problem is *code review* better at finding compared with *architectural risk analysis*?
- Why is risk analysis difficult to do at the coding level?
- What is the main drawback of penetration testing, especially when it is applied as an absolute measure of security of a software system?

References and credits

Material in this lecture is adapted from

- *Software Security: Building Security In*, by Gary McGraw. Addison-Wesley, 2006.
- *The Art of Software Security Testing*, by Wysopal, Nelson, Dai Zovi and Dustin. Addison-Wesley, 2007.
- *Build Security In*, the initiative of US-CERT and now re-branded as *Secure by Design* by the US Cyber Defense Agency CISA, see https://www.cisa.gov/securebydesign.

Recommended reading

- Microsoft's STRIDE approach originally documented in the MSDN magazine, Nov 2006. See the Wikipedia page.
- Saltzer and Shroeder. *The Protection of Information in Computer Systems*, 1975. Web version available at MIT Proceedings of IEEE version at IEEE Explore.
- The **DevOps** revolution lets developers deploy directly and update rapidly; **DevSecOps** brings security into the CI/CD process, as a mix of automated security testing, analysis and vulnerability tracking. See e.g., Microsoft's advice.
- The CyBoK Secure Software Lifecycle Knowledge Area KA gives an overview of the topic area and plenty of pointers.