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UNIVERSITÉ Grenoble Alpes

Grenoble INP Ensimag

Software security, secure programming

Conclusion

Master M2 Cybersecurity

Academic Year 2025 - 2026

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A multi-level issue . . .

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. . . enhanced by the (incorrect) use of insecure languages

- importance of **type safety** and **memory safety**
- trade-off between safety/security and run-time efficiency
  (execution time, resource consumption)

↪ things may move slowly (JavaScript → TypeScript; C → Rust?)

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  - (lightweight) runtime error detection tools
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↪ widely deployed on main stream execution platforms . . .
but take care with more specific ones (IoT, Scada, etc.)!

Code analysis techniques & tools

Goals

- vulnerability detection
- vulnerability analysis (e.g., to evaluate their exploitability level)
- reverse-engineering and/or forensic analysis assistance
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- static techniques: syntax-checking, pattern detection, static analysis
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And still a challenging issue to analyse binary code . . .

Outline

What have been seen?

Future trends?

A few words on CodeQL

A few words on machine-learning techniques

Software vulnerabilities

Probably **not over** in a near future . . .
(endless cat and mouse games between attackers & defenders)

but:

- “basic” vulnerabilities (BoF, arithmetic overflows, etc) should become less proeminent . . .
- more HW/SW security issues?

Vulnerability **exploitation** should become more and more difficult on **recent** execution plateforms . . .

but still a huge panel of **legacy/unprotected** hardware and software (e.g., in industrial systems)

Vulnerability detection & analysis tools

For the code developers

From DevOps to DevSecOps, with a potential increase of:

- fuzzing, including for side-channels, low-level vulnerabilities
- pattern-based detection tool (like Semgrep, CodeQL)
- machine-learning techniques . . .

For the code auditors &security experts

Towards (smarter) combinations of:

- fuzzing, dynamic-symbolic execution and static analysis
- machine-learning techniques . . .

Possibly with an emphasis on quantitative analysis
(**how much** dangerous is a vulnerability?)

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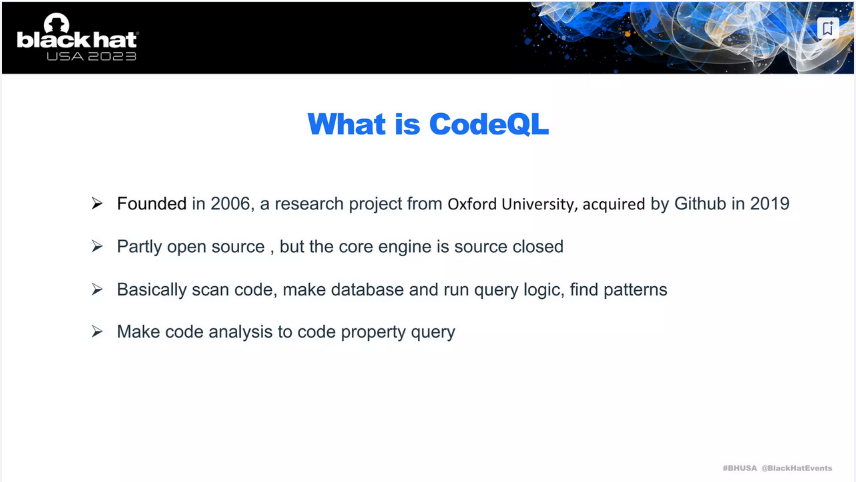
CodeQL: an example of pattern-detection tool

- static analysis (no code execution!)

- allows to find “arbitrary” **patterns** on (large) code bases
  ↪ e.g., to look for existing CWEs

- offer a powerful **query language** for pattern description allowing to mix syntactic and semantic features, including:
  - data-flow analysis
  - range analyis
  - alias analysis
  - etc.

- easy to integrate within a CD/CI pipeline . . .

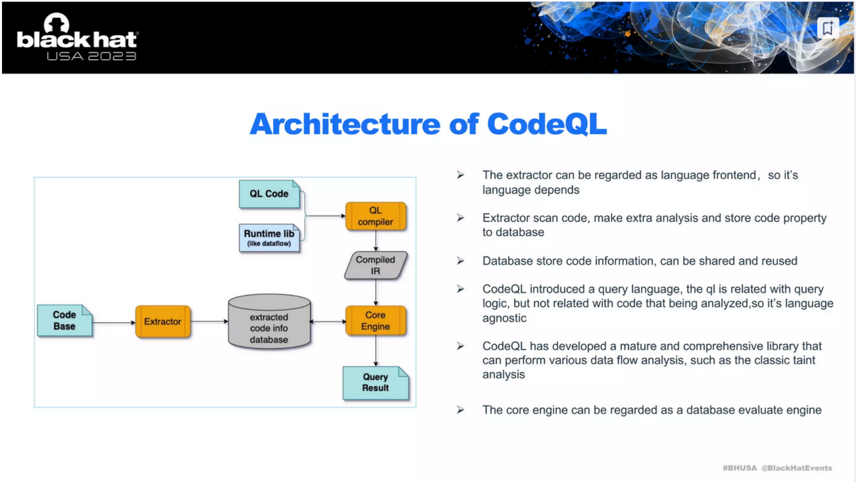


What is CodeQL

- Founded in 2006, a research project from Oxford University, acquired by Github in 2019
- Partly open source , but the core engine is source closed
- Basically scan code, make database and run query logic, find patterns
- Make code analysis to code property query

#BHUSA @BlackHatEvents

[Credits: H. Zhang, **CodeQL: also a powerful binary analysis engine** - BlackHat 2023]



Architecture of CodeQL

- The extractor can be regarded as language frontend， so it's language depends
- Extractor scan code, make extra analysis and store code property to database
- Database store code information, can be shared and reused
- CodeQL introduced a query language, the ql is related with query logic, but not related with code that being analyzed,so it's language agnostic
- CodeQL has developed a mature and comprehensive library that can perform various data flow analysis, such as the classic taint analysis
- The core engine can be regarded as a database evaluate engine

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Query examples and demo

Example of C/C++ publicly available queries

Demo of a use-after-free query . . .

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Examples of ML applications for cybersecurity

ML techniques

- **supervised ML:**
  Use **labeled dataset** to train algorithms and define the variables to be assessed for correlations (input/outputs being specified). Model weights can be adjusted to avoid overfitting or underfitting.
- **reinforcment ML:**
  Train the algorithm by **trial and error** rather than using sample data.
- **unsupervised ML** (used for deep-learning):
  Analyze and cluster **unlabeled datasets** to identify hidden patterns or data clustering.

Application to Cybersecurity

- Intrusion detection (computer, network)
- Malware/ransomware detection & recognition
- Log aggregation/corelation & alert analysis (e.g. in SIEM systems)
- automated pen-testing (!) [see the paper])
- **vulnerability** detection and analysis . . .
- automated **secure code** generation, **exploit** generation (?) . . .

ML classification techniques for vulnerability detection/analysis

Main challenges

- get a rather **balanced** sets of (labeled?) vulnerable & non vulnerable code examples
- relevant code features include **data-flow** and **control-flow** information, to be properly extracted & processed to feed the models

Main applications

- vulnerability **detection** (or simply "vulnerable code" detection . . .)
- reverse engineering: function detection, type identification, binary diffing, etc.
- enhanced code analysis techniques (fuzzing, pattern recognition)
- side-channel & information leakage detection
- etc.

examples of (not too old) papers

A typical Vulnerability detection tool

VulDeePecker: A Deep Learning-Based System for Vulnerability Detection (NDDS Conference, 2018)

Using LLMs for secure code generation

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  This study investigated the security of code generated by Large Language Models (LLMs). We designed a set of prompts and evaluated the code generated by ten different LLMs, encompassing both closed-source and open-source models [...]. ***The results revealed a concerning number of Common Weakness Enumerations (CWEs) in the generated code.*** *Among the most critical vulnerabilities identified were CWE-120: Buffer Copy without Checking Size of Input, CWE-787: Out-of-bounds Write, CWE-122: Heap-based Buffer Overflow, CWE-252: Unchecked Return Value, CWE-190: Integer Overflow or Wraparound, and CWE-401: Missing Release of Memory after Effective Lifetime*

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- automated secure code generation (2) (Usenix 25 paper) *Our experiments and findings highlight****package hallucinations as a persistent and systemic phenomenon*** *while using state-of-the-art LLMs for code generation, and a significant challenge which deserves the research community's urgent attention*

So, what about ML for Software Security?

Not yet the “definite solution” for vulnerability detection/analysis:

- hard to evaluate and compare with other existing techniques
- lack of result explainability
  (e.g., correctly locating vulnerable statements?)
- what about new vulnerability patterns?

But clearly a promising and essential research direction . . .
in conjunction with classical techniques

A possible next challenging (and more practical) step:
using generative IA to produce secure-by-construction software?

Credits

A Survey on Machine Learning Techniques for Cyber Security in the Last Decade - K. Shaukat et al- IEEE Access 2020

Machine learning (ML) in cybersec2yyurity - SailPoint

ML4Sec papers

Software Security Analysis in 2030 and Beyond: A Research Roadmap