Determining the Fundamental Basis of Software Vulnerabilities

Larry Wagoner
NSA

Agenda

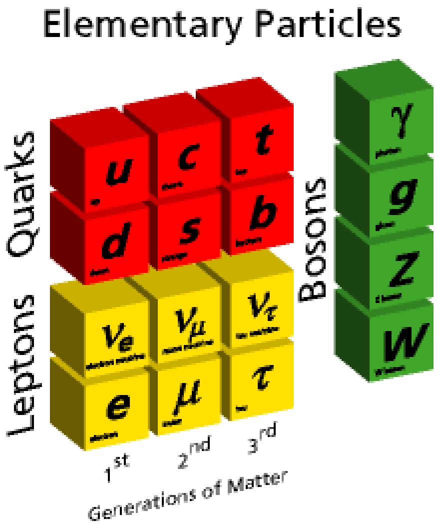
- Background
  - Analogous background
  - Matt Bishop work
  - CWEs
  - Tool reporting of CWEs
  - KDM Analytics
- Determining the fundamental basis

Elements of the world

- Classical elements in Babylonia (~17 B.C.): Sea, Earth, Fire, Sky and Wind
- Greek Classical Elements:
  - Four terrestrial elements: Earth, Water, Air and Fire
  - Sometimes a fifth element, Aether, was added
    - Aether is “pure, fresh air” or “clear sky”
  - Persisted throughout the middle ages
- Now viewed as a simplistic view of the world

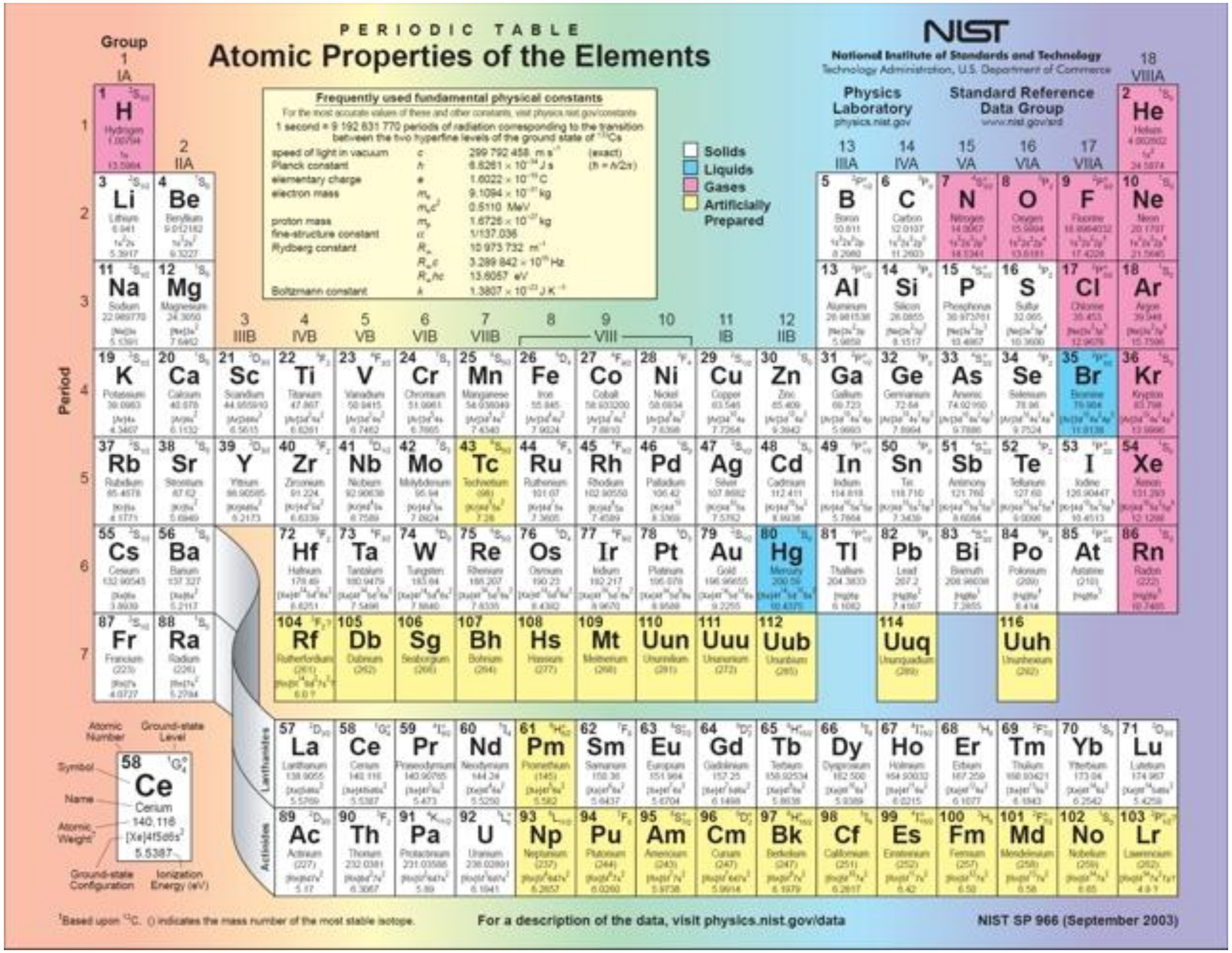
More modern view

- Basic building blocks of matter
  - Atoms
    - Protons, neutrons, electrons
  - Elementary particles
    - Quarks, leptons, bosons



Periodic Table of Chemical Elements

Presented by the number of protons in
the atom’s nucleus



PERIODIC TABLE

Atomic Properties of the Elements

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Physics Laboratory
physics.nist.gov

Standard Reference Data Group
www.nist.gov/srd

Frequently used fundamental physical constants

Solids
Liquids
Gases
Artificially Prepared

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub		114 Uuq		116 Uuh		

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

¹Based upon ¹²C. ( ) indicates the mass number of the most stable isotope.

For a description of the data, visit physics.nist.gov/data

NIST SP 966 (September 2003)

WHAT ARE THE ELEMENTARY BUILDING BLOCKS OF SOFTWARE VULNERABILITIES?

“Vulnerabilities Analysis”

- M. Bishop, “Vulnerabilities Analysis,” *Proceedings of the Second International Symposium on Recent Advances in Intrusion Detection* pp. 125–136 (Sep. 1999).
- Goal was to develop a classification scheme for vulnerabilities
- Scheme is deterministic
  - Each class has exactly one property
  - “yes” or “no” answer for membership
- Classification based on the code, environment or other technical details
  - Social cause is not a valid class
- Seeking consistent classification

Data and Stack Buffer Overflow Breakdown (Bishop)

- A buffer overflow attack can be decomposed into primitive conditions that must exist for the attack to succeed
- Stop any of the primitive conditions and the attack cannot succeed
- Four primitive conditions in *fingerd* attack on Unix system
  - C1. Failure to check bounds when copying data into a buffer.
  - C2. Failure to prevent the user from altering the return address.
  - C3. Failure to check that the input data was of the correct form (user name or network address).
  - C4. Failure to check the type of the words being executed (data loaded, not instructions).

Invalidating these conditions prevents the exploitation (Bishop)

- C1’. If the attacker cannot overflow the bounds, the control flow will continue in the text (instruction) space and not shift to the loaded data.
- C2’. If the return address cannot be altered, then even if the input overflows the bounds, the control flow will resume at the correct place.
- C3’. As neither a user name nor a network address is a valid sequence of machine instructions on most UNIX systems, this would cause a program crash and not a security breach.
- C4’. If the system cannot execute data, the return into the stack will cause a fault. (Some vendors have implemented this negation, so data on the stack cannot be executed. However, data in the heap can be, leaving them vulnerable to attack.)

Common Weakness Enumeration (MITRE)

- Dictionary of software weaknesses
- Amalgamation of over a dozen taxonomies
  - CLASP, PLOVER, Pernicious Kingdoms, etc.
- Approximately 807 weaknesses or weakness categories described
- Example: CWE-120: Buffer Copy without Checking Size of Input ('Classic Buffer Overflow')
  - The program copies an input buffer to an output buffer without verifying that the size of the input buffer is less than the size of the output buffer, leading to a buffer overflow.

Reporting of CWEs

- Consider:

```
/* Stack Overflow */
#define BUFSIZE 256
int main(int argc, char **argv) {
   char buf[BUFSIZE];
   strcpy(buf, argv[1]);
}
```

- Is the vulnerability:
  - CWE-121 Stack based Buffer Overflow

  or

  - CWE-20 Improper Input Validation?

Software Fault Patterns

- Pilot by DoD, NIST and DHS
  - Develop a specification of software vulnerabilities that enables automation
  - Looked at subset of CWEs that could potentially be automated
    - Those that can be formalized
    - 302 CWEs
  - Clustered 302 CWEs into 50 software fault patterns
  - Developed whitebox definitions of a small number of CWEs
  - Formalization (machine readable) of 18 CWEs
  - Side effect of work identified a set of 81 Vulnerability Fundamentals

Fundamental Vulnerabilities

- Fundamental Vulnerability (FV) – A primitive condition in software that can serve as the basis for exploitation of the software
- FVs are defined in the format of a statement of fact
- An FV is the root cause of a software exploitation
- One or more FVs need to be exploited in order for an attack to occur
- An attack can be disrupted if one or more in a series of FVs is removed

Consider Buffer Overflow

- C1 (Bishop). Failure to check bounds when copying data into a buffer.
- FV: Check of array bounds before array access does not exist or is faulty
- C2 (Bishop). Failure to prevent the user from altering the return address.
- FV: Direct access to a memory address is permitted (can use/alter address of memory to access memory)
- C3 (Bishop). Failure to check that the input data was of the correct form (user name or network address).
- FV: Input checks do not exist or are faulty
- C4 (Bishop). Failure to check the type of the words being executed (data loaded, not instructions).
- FV: Code and data are indistinguishable in memory (commands are treated as data)

A Buffer Overflow Cannot Occur if…

- If a check of array bounds is performed correctly before the access
  - FV: Check of array bounds before array access does not exist or is faulty
- If memory addresses cannot be directly accessed or altered
  - FV: Direct access to a memory address is permitted (can use/alter address of memory to access memory)
- If input is validated correctly
  - FV: Input checks do not exist or are faulty
- If code and data is segregated in memory
  - FV: Code and data are indistinguishable in memory (commands are treated as data)

CWEs and FVs

- CWE-369 Divide by Zero
  - FV: Check that divisor is not 0 before division is performed does not exist or is faulty
- CWE-732 Incorrect Permission Assignment for Critical Resource
  - FV: Check of permissions do not exist or are faulty
- CWE-561 Dead Code
  - FV: Code exists in a program that is not on any execution path

FVs Rooted in Language Structure

- FV: There is a duality of a string and a null terminated array
- FV: There is syntactic ambiguity in the language
- FV: Signed and unsigned data types are converted from one the other
- FV: There is a disconnect between a pointer and the resource that it represents

FVs Across a Variety of Languages

- FV: Input checks do not exist or are faulty
- FV: Return value check does not exist or is faulty
- FV: Variable is used before it is initialized
- FV: Binary compilation is not functionally equivalent to its source
- FV: Hardware is not standardized
  - size of short, int, long differ between platforms

FVs Interaction with Environment

- FV: Security check is not performed local to the application
  - Security check is performed on client for a server application
- FV: Interface with another language is inconsistent

FVs Resource Interaction

- FV: Ownership of a resource expires
  - Memory containing sensitive information can then be read by some other program
- FV: History and provenance is not available for use at authentication points
  - No basis for determining the integrity of dynamically linked resource
- FV: Race condition for shared resource exists

Current Status

- About 70 FVs have been identified
- List has been mapped against the 2011 CWE/SANS Top 25 Most Dangerous Software Errors
- List is still being refined and expanded

Thank you.