CS 465

AES

Programming Lab #1

- Implement AES
- Use the FIPS 197 spec as your guide
  - Avoid looking at code on the Internet
  - Challenge yourself to implement the algorithm based on sources mentioned in the lab specification
  - The standard provides programming language independent pseudo-code
  - 20 pages in the spec of complete, step by step debugging information to check your solution

Finite Fields

- AES uses the finite field GF(2^8)
  - $b_7x^7 + b_6x^6 + b_5x^5 + b_4x^4 + b_3x^3 + b_2x^2 + b_1x + b_0$
    - $\{b_7, b_6, b_5, b_4, b_3, b_2, b_1, b_0\}$
- Byte notation for the element: $x^6 + x^5 + x + 1$
  - $0x^7 + 1x^6 + 1x^5 + 0x^4 + 0x^3 + 0x^2 + 1x + 1$
  - {01100011} – binary
  - {63} – hex
- Has its own arithmetic operations
  - Addition
  - Multiplication

Finite Field Arithmetic

- Addition (XOR)
  - $(x^6 + x^4 + x^2 + x + 1) + (x^7 + x + 1) = x^7 + x^6 + x^4 + x^2$
  - $\{01010111\} \oplus \{10000011\} = \{11010100\}$
  - $\{57\} \oplus \{83\} = \{d4\}$

- Multiplication is tricky

Finite Field Multiplication (•)

$(x^6 + x^4 + x^2 + x + 1)(x^7 + x + 1) =$

These cancel out

$$x^{13} + x^{11} + x^9 + x^8 + x^7 + x^7 + x^5 + x^3 + x^2 + x + x^6 + x^4 + x^2 + x + 1$$

$$= x^{13} + x^{11} + x^9 + x^8 + x^6 + x^5 + x^4 + x^3 + 1$$

and

$x^{13} + x^{11} + x^9 + x^8 + x^6 + x^5 + x^4 + x^3 + 1$ modulo $(x^8 + x^4 + x^3 + x + 1)$

$= x^7 + x^6 + 1.$

Irreducible Polynomial

Efficient Finite Field Multiply

- There's a better way
  - xtime() – very efficiently multiplies its input by {02}
    - This is the same as multiplying a polynomial by x
- Multiplication by higher powers can be accomplished through repeated applications of xtime()

Efficient Finite Field Multiply

Example: {57} • {13}

{57} • {02} = xtime({57}) = {ae}

{57} • {04} = xtime({ae}) = {47}

{57} • {08} = xtime({47}) = {8e}

{57} • {10} = xtime({8e}) = {07}

{57} • {13} = {57} • ({01} ⊕ {02} ⊕ {10})

= {57} • ({01} ⊕ {02} ⊕ {10})

= ({57} • {01}) ⊕ ({57} • {02}) ⊕ ({57} • {10})

= {57} ⊕ {ae} ⊕ {07}

= {fe}

AES Parameters

- Nb – Number of columns in the State
  - For AES, Nb = 4
- Nk – Number of 32-bit words in the Key
  - For AES, Nk = 4, 6, or 8
- Nr – Number of rounds (function of Nb and Nk)
  - For AES, Nr = 10, 12, or 14

AES methods

- Convert to state array
- Transformations (and their inverses)
  - AddRoundKey
  - SubBytes
  - ShiftRows
  - MixColumns
- Key Expansion

Inner Workings

- See Flash demo URL on course **Lectures** pages