# ECEN 4133



Side channel attacks and defenses

# Side channel

- Measure something secret using other available ***indirect measurement***
- Secrets:
  - Passwords
  - Private keys
  - Confidential information
- Available data:
  - Timing
  - Power
  - Heat
  - Sound
  - Pizza deliveries…???
    - Panama invasion (1990)
    - Operation Desert Storm (1991)



# Side channel example: passwords

```
bool check_password(char *pw, char *correct) {
     if (strlen(pw)!=strlen(correct))
          return false;
     for (int i=0; i<strlen(pw); i++) {
          if (pw[i] != correct[i]) return false;
     }
     return true;
}
```

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        }
        return true;
}
```



```
check_password(“aaa”, “s3cr37”) => 10us
check_password(“aaaaaa”, “s3cr37”) => 15us
check_password(“baaaaa”, “s3cr37”) => 15us
check_password(“saaaaa”, “s3cr37”) => 20us
```

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        if (strlen(pw)!=strlen(correct))
                return false;
        for (int i=0; i<strlen(pw); i++) {
                if (pw[i] != correct[i]) return false;
        }
        return true;
}
```



check_password(“saaaaa”, “s3cr37”) => 20us

check_password(“s3aaaa”, “s3cr37”) => 25us

How many guesses to get correct N-character password?

# Side channel example: passwords

- How should we fix this vulnerability?

# Side channel solution: constant time

```
// Note: strlen(correct) must be equal to strlen(pw)
// This function still leaks the length of strlen(correct)!
//              (how could we fix?)
bool check_password(char *pw, char *correct) {
        if (strlen(pw) != strlen(correct)) return false;
        int diff = 0;
        for (int i=0; i<strlen(pw); i++) {
                diff |= (pw[i] ^ correct[i]);
        }
        return (diff == 0);
}
```

- check_password(“XXXXXXXXXXX”, “longpassword”) and check_password(“longpassworX”, “longpassword”) should take the same amount of time!

# Side channel example: repeated squaring

- Recall RSA decryption/signatures:
  - sig = x^d mod N
  - Where d is a very large number (~2048 bits)
  - Can't write a for loop for this: for (i=0; i<d; i++) { } … never completes (or takes 10^600 years)
  - So how do we compute x^d mod N?

# Side channel example: repeated squaring

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  - So how do we compute x^d mod N?
    - Observe that:
      - x^10 == (x^2)^5 == (x^2)*(x^2)^4 == (x^2)*((x^2)^2)^2
      - Similarly: x^256 = (((((((x²)²)²)²)²)²)²)²)²)²)
        x^257 = (((((((x²)²)²)²)²)²)²)²)²)*x
      - x^d should only take log(d) multiplications and/or squaring!

$$x^n = \begin{cases} x\left(x^2\right)^{\frac{n-1}{2}}, & \text{if } n \text{ is odd} \\ \left(x^2\right)^{\frac{n}{2}}, & \text{if } n \text{ is even.} \end{cases}$$

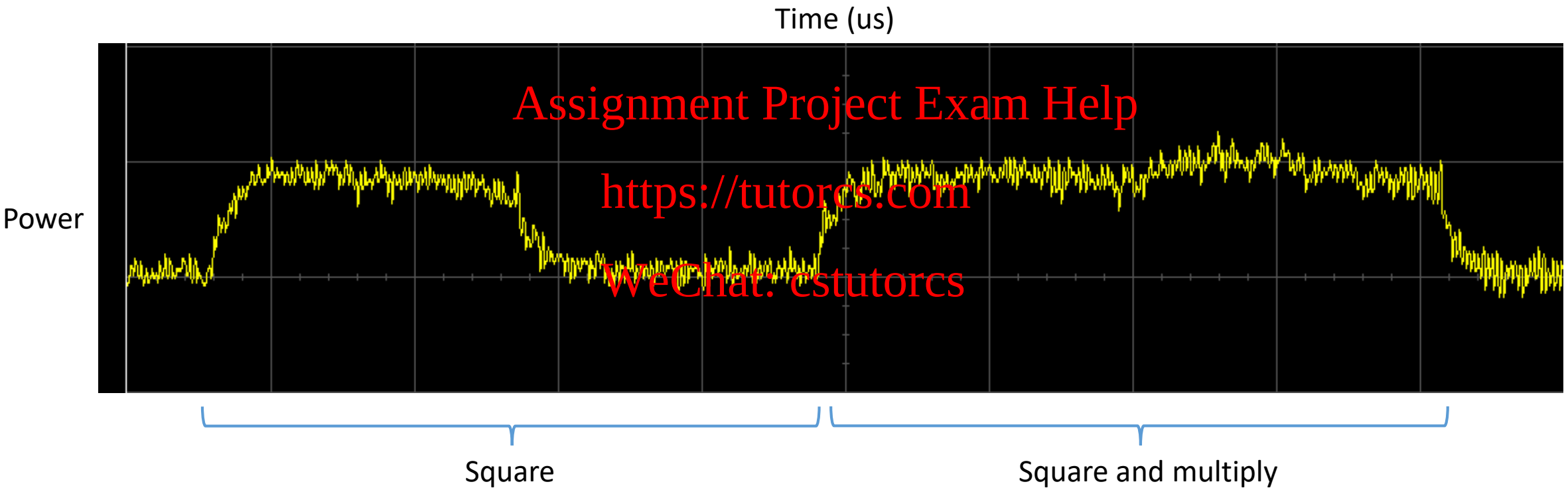
# Side channel example: repeated squaring

```
def exp(x, n):
      if n = 0 then return 1
      y = 1;
      while n > 1:
            if n%2==1:  # n is odd
                  y = x * y;
                  x = x * x;
                  n = (n - 1) / 2;
            else:       # n is even
                  x = x * x;
                  n = n / 2;
      return x * y
```



$$x^n = \begin{cases} x\,(x^2)^{\frac{n-1}{2}}, & \text{if } n \text{ is odd} \\ (x^2)^{\frac{n}{2}}, & \text{if } n \text{ is even.} \end{cases}$$

# Side channel example: repeated squaring



- Solving the repeated squaring side channel?

# Repeated squaring: Montgomery's Ladder:

```
x1 = x
x2 = x*x
for i = k - 2 to 0:        # k bits in n, MSB (n_(k-1)) = 1
        if n_i == 0:       # bit is even
                x2 = x1*x2
                x1 = x1*x1
        else:              # bit is odd
                x1 = x1*x2
                x2 = x2*x2
return x1
```

# Alternative side channel defense: blinding

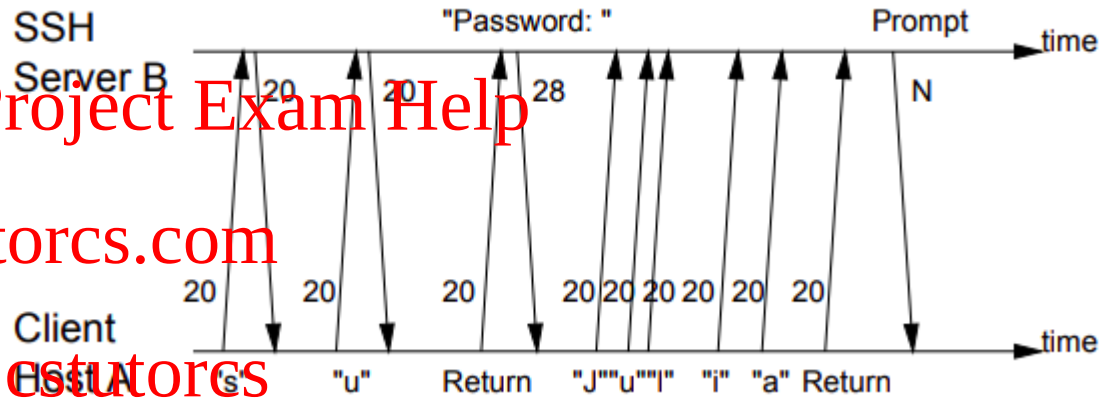
- Given c = x^e mod N
- Don’t want to compute c^d mod N (might leak d!)
- First **blind**: b = c*r^e mod N for random r (this is just (xr)^e mod N)
- Then decrypt: a = b^d mod N = (xr)^ed mod N = xr mod N
- Remove blinding: a*r^-1 mod N = xr*r^-1 mod N = x mod N
- Since attacker doesn’t know r, can’t learn d during “blinded” decryption

# Other side channels?

- What other examples of side channels exist?
- How can we fix them?

# Other side channels?

- EM-emission
- Sound
- Accelerometer data
- Timing of key presses
- Shared resources:
  - Cache timing
  - Bandwidth / latency
  - IPID field in IP packets



# Cache side channels

- Caches improve performance by storing recently-accessed data close to the CPU
- *Potentially leaks what was recently accessed!*



1. **Attacker** fills cache:

| |
|---|
| 0xA0 |
| 0xA4 |
| 0xA8 |
| 0xAC |

2. **Victim process** reads from 0xC8:

| |
|---|
| 0xA0 |
| 0xA4 |
| 0xC8 |
| 0xAC |

0xA8 is evicted

3. **Attacker** reads:

0xA0 (52ns)
0xA4 (55ns)
**0xA8 (397ns)** →
0xAC (49ns)

Attacker learns **0xA8** was not in cache!
(recently evicted by another process)

AES S-box

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0a | 0b | 0c | 0d | 0e | 0f |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | 63 | 7c | 77 | 7b | f2 | 6b | 6f | c5 | 30 | 01 | 67 | 2b | fe | d7 | ab | 76 |
| 10 | ca | 82 | c9 | 7d | fa | 59 | 47 | f0 | ad | d4 | a2 | af | 9c | a4 | 72 | c0 |
| 20 | b7 | fd | 93 | 26 | 36 | 3f | f7 | cc | 34 | a5 | e5 | f1 | 71 | d8 | 31 | 15 |
| 30 | 04 | c7 | 23 | c3 | 18 | 96 | 05 | 9a | 07 | 12 | 80 | e2 | eb | 27 | b2 | 75 |
| 40 | 09 | 83 | 2c | 1a | 1b | 6e | 5a | a0 | 52 | 3b | d6 | b3 | 29 | e3 | 2f | 84 |
| 50 | 53 | d1 | 00 | ed | 20 | fc | b1 | 5b | 6a | cb | be | 39 | 4a | 4c | 58 | cf |
| 60 | d0 | ef | aa | fb | 43 | 4d | 33 | 85 | 45 | f9 | 02 | 7f | 50 | 3c | 9f | a8 |
| 70 | 51 | a3 | 40 | 8f | 92 | 9d | 38 | f5 | bc | b6 | da | 21 | 10 | ff | f3 | d2 |
| 80 | cd | 0c | 13 | ec | 5f | 97 | 44 | 17 | c4 | a7 | 7e | 3d | 64 | 5d | 19 | 73 |
| 90 | 60 | 81 | 4f | dc | 22 | 2a | 90 | 88 | 46 | ee | b8 | 14 | de | 5e | 0b | db |
| a0 | e0 | 32 | 3a | 0a | 49 | 06 | 24 | 5c | c2 | d3 | ac | 62 | 91 | 95 | e4 | 79 |
| b0 | e7 | c8 | 37 | 6d | 8d | d5 | 4e | a9 | 6c | 56 | f4 | ea | 65 | 7a | ae | 08 |
| c0 | ba | 78 | 25 | 2e | 1c | a6 | b4 | c6 | e8 | dd | 74 | 1f | 4b | bd | 8b | 8a |
| d0 | 70 | 3e | b5 | 66 | 48 | 03 | f6 | 0e | 61 | 35 | 57 | b9 | 86 | c1 | 1d | 9e |
| e0 | e1 | f8 | 98 | 11 | 69 | d9 | 8e | 94 | 9b | 1e | 87 | e9 | ce | 55 | 28 | df |
| f0 | 8c | a1 | 89 | 0d | bf | e6 | 42 | 68 | 41 | 99 | 2d | 0f | b0 | 54 | bb | 16 |

The column is determined by the least significant nibble, and the row by the most significant nibble. For example, the value $9a_{16}$ is converted into $b8_{16}$.