CSc 466/566

Computer Security

8 : Man-At-The-End — Obfuscation II

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Dynamic Obfuscation

Static vs. Dynamic obfuscation

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Dynamic Obfuscation: Definitions

- A dynamic obfuscator runs in two phases:
  1. At compile-time transform the program to an initial configuration and add a runtime code-transformer.
  2. At runtime, intersperse the execution of the program with calls to the transformer.

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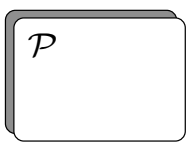
  2. At runtime, intersperse the execution of the program with calls to the transformer.
- A dynamic obfuscator turns a "normal" program into a self-modifying one.

Modeling dynamic obfuscation — compile-time



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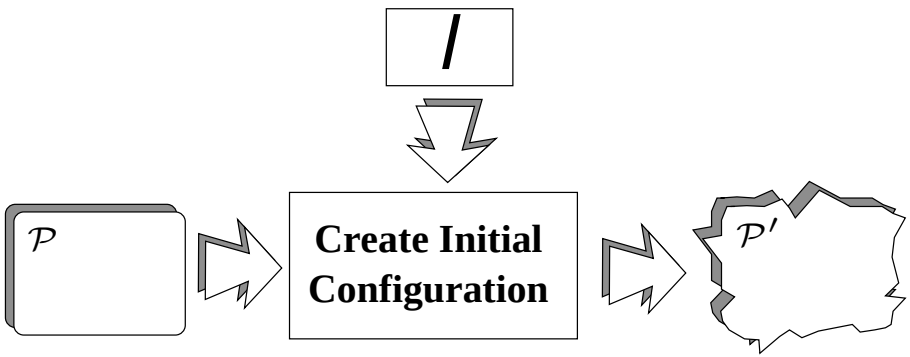

- Transformer I creates $\mathcal{P}$'s initial configuration.

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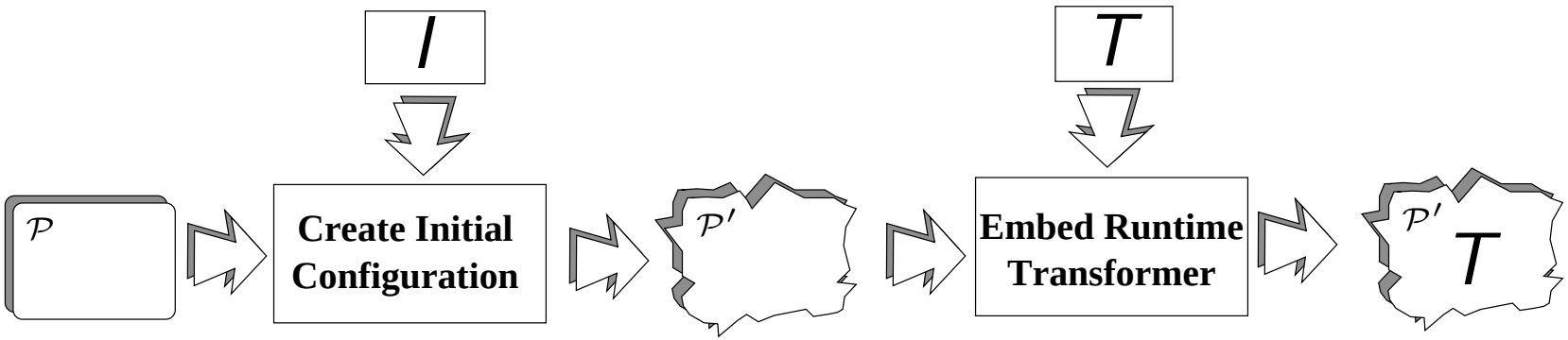
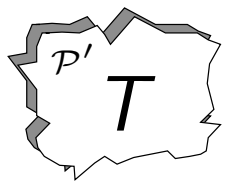


- Transformer I creates $\mathcal{P}$'s initial configuration.
- T is the runtime obfuscator, embedded in $\mathcal{P}'$.

Modeling dynamic obfuscation — runtime



- Transformer T continuously modifies $\mathcal{P}'$ at runtime.

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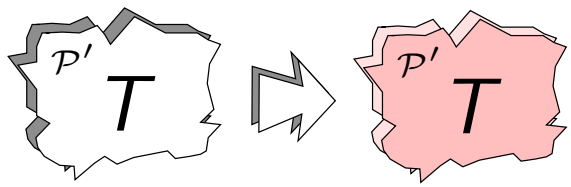

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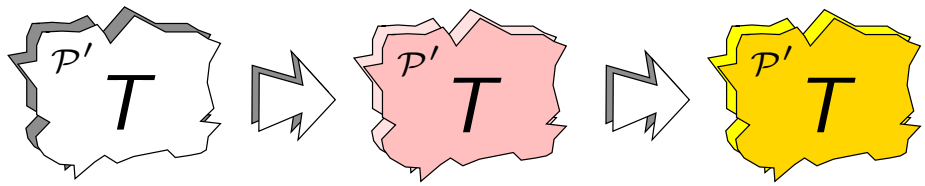

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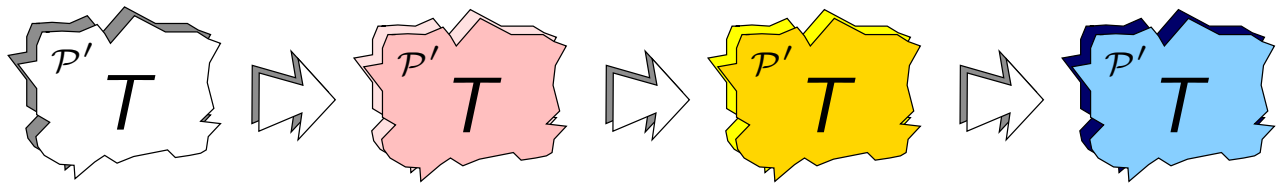

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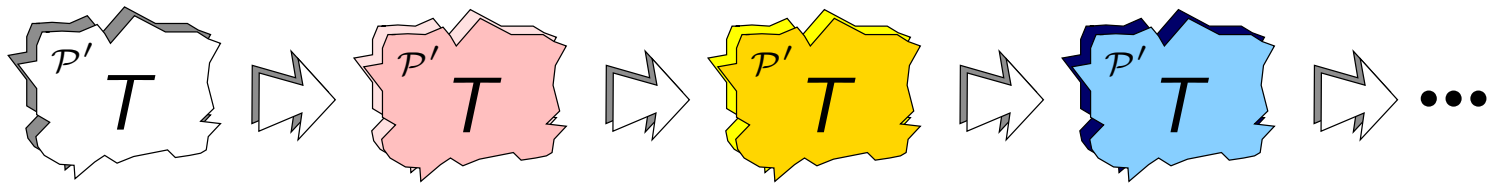

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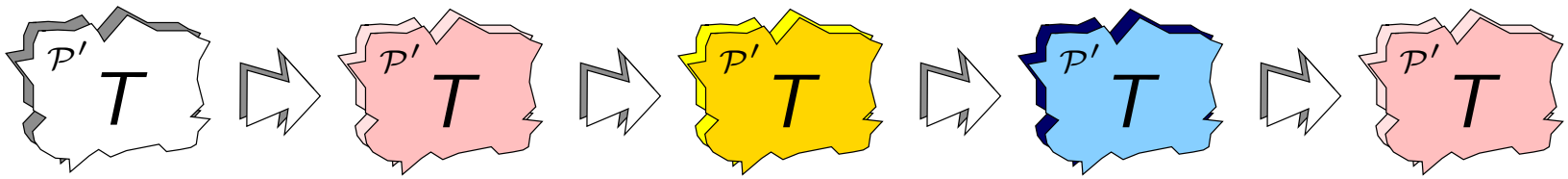


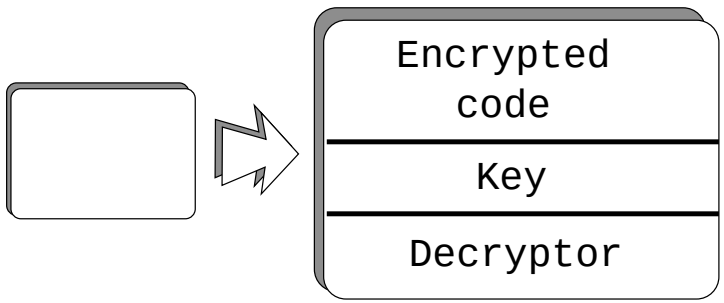
- Transformer T continuously modifies $\mathcal{P}'$ at runtime.
- We'd like an infinite, non-repeating series of configurations.
- In practice, the configurations repeat.

Algorithm Ideas

Basic algorithm ideas

- Build-and-execute: generate code for a routine at runtime, and then jump to it.
- Self-modification: modify the executable code.
- Encryption: The self-modification is decrypting the encrypted code before executing it.
- Move code: Every time the code executes, it is in different location.

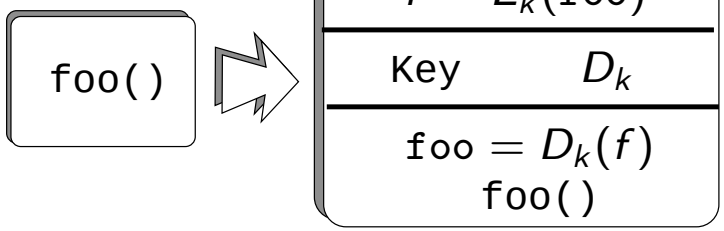
File-Level Encryption: Packers




```
> find key
> find decryptor
> decrypt
```

- Packers are simple tools that encrypt the binary, and include a routine that will decrypt at runtime.

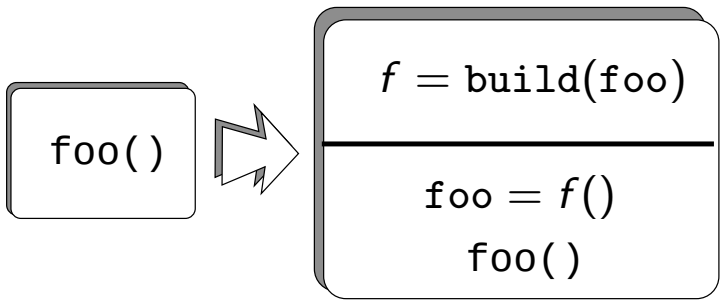
Function-Level Encryption

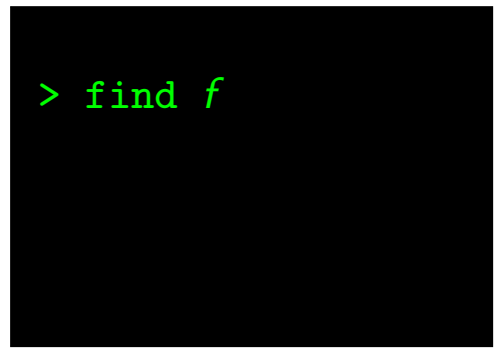



```
> find key
> find D_k
> find f
> decrypt
```

- You can also decrypt a function just before it gets called.

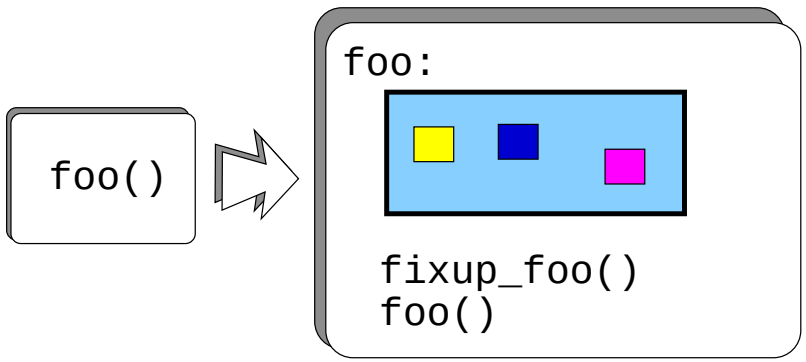
Build-And-Execute





- You can generalize "encryption" to any embedded function that constructs the "real" code at runtime.

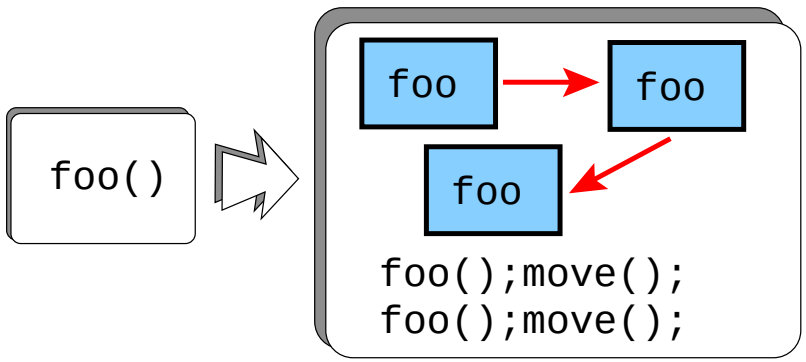
Self-Modifying Code

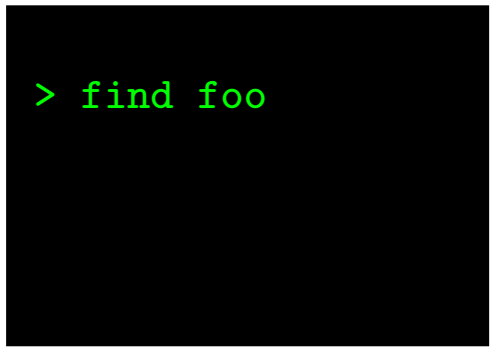



```
> find foo
> find fixup_foo
```

- Leave “holes” in `foo`, fix them just before `foo` gets called.

Move Code Around





- Continously move code around to make it harder to find.

Granularity

- These operations can be applied at different levels of granularity:
  - File-level
  - Function-level
  - Basic block-level
  - Instruction-level

Attack Goals

- The attacker's goal can be to:
  - recover the original code
  - modify the original code

```
int modexp(int y, int x[], int w, int n, int mode) {
    int R, L, k = 0, s = 1, t;
    char* p=&&begin;
    while (p<(char*)&&end) *p++ ^= 99;
    if (mode==1) return 0;
    while (k < w) {
        begin:
            ... ... ...
            ... ... ...
        end:
        k++;
    }
    p=&&begin; while (p<(char*)&&end) *p++ ^= 99;
    return L;
}
int main() {
    makeCodeWritable(···);
    modexp(0, NULL, 0, 0, 1);
    ...
    modexp(···, ···, ···, ···, 0);
```

Code Explanation

- The blue code is xor:ed with a key (99).
- When the code is to be executed it gets "decrypted", executed, and re-encrypted.
- The green code would normally execute at obfuscation time.
- Every subsequent time the `modexp` routine gets called the pink code first decrypts the blue code, executes it, and then the yellow code re-encrypts it.

Practical issues

- Pages have to be modifiable and executable. (See next slide).
- You have to flush the CPU's data cache before executing new code you have generated. (Why?) X86 does this automatically.

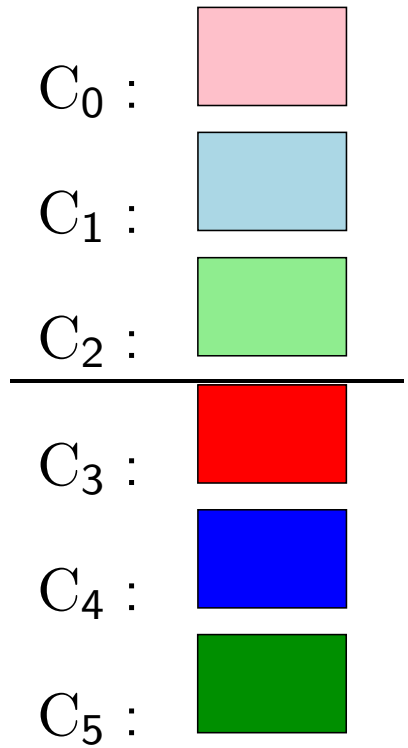
```
void makeCodeWritable(caddr_t first, caddr_t last)
    caddr_t firstpage =
        first - ((int)first % getpagesize());
    caddr_t lastpage =
        last - ((int)last % getpagesize());
    int pages=(lastpage-firstpage)/getpagesize()+1;
    if (mprotect(
            firstpage,
            pages*getpagesize(),
            PROT_READ|PROT_EXEC|PROT_WRITE
         )==-1)
             perror("mprotect");
}
```

Decrypting by Emulation

- "Encrypting" binaries is often re-invented!
- Attack: run the program inside an emulator that prints out every executed instruction.
- The instruction trace can be analyzed (re-rolling loops, removing decrypt-and-jump artifacts, etc.) and the original code recovered.

Self-Modifying State Machine

Aucsmith's algorithm



- A function is split into cells.

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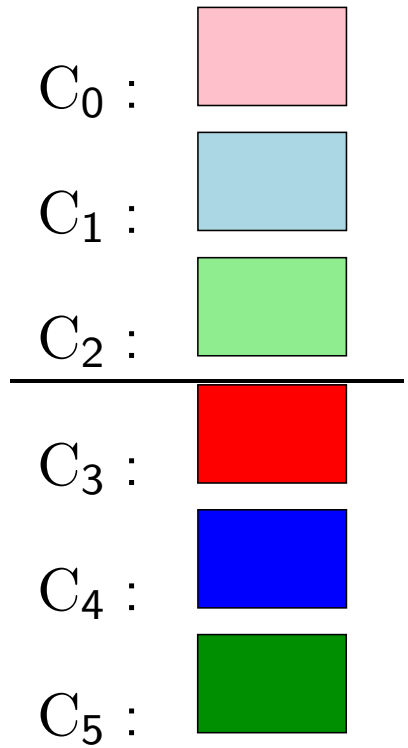
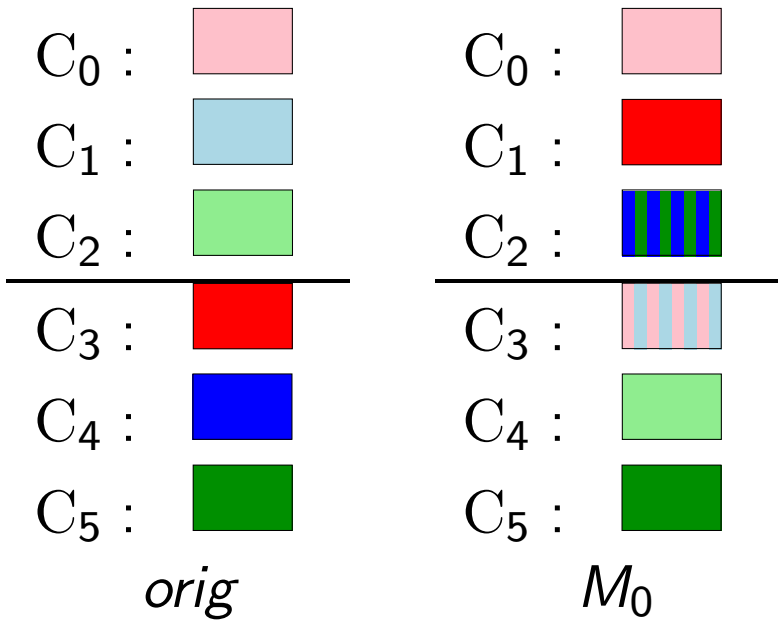
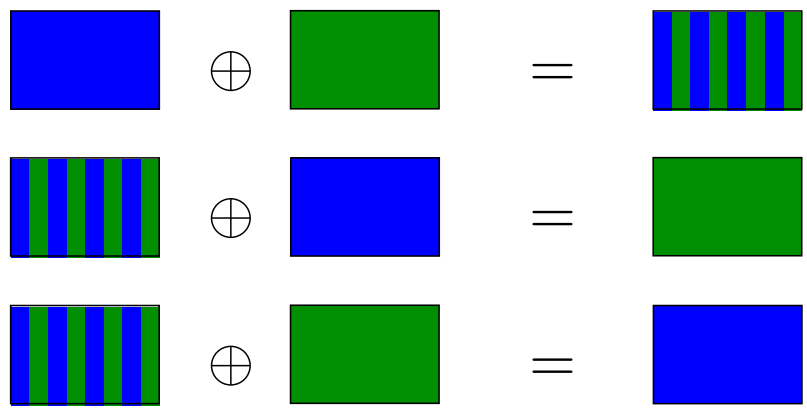


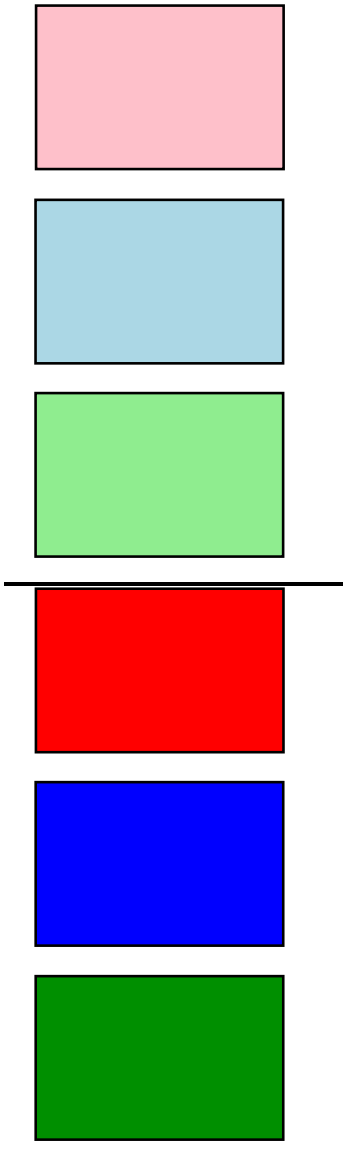
- A function is split into cells.
- The cells are divided into two regions in memory, upper and lower.

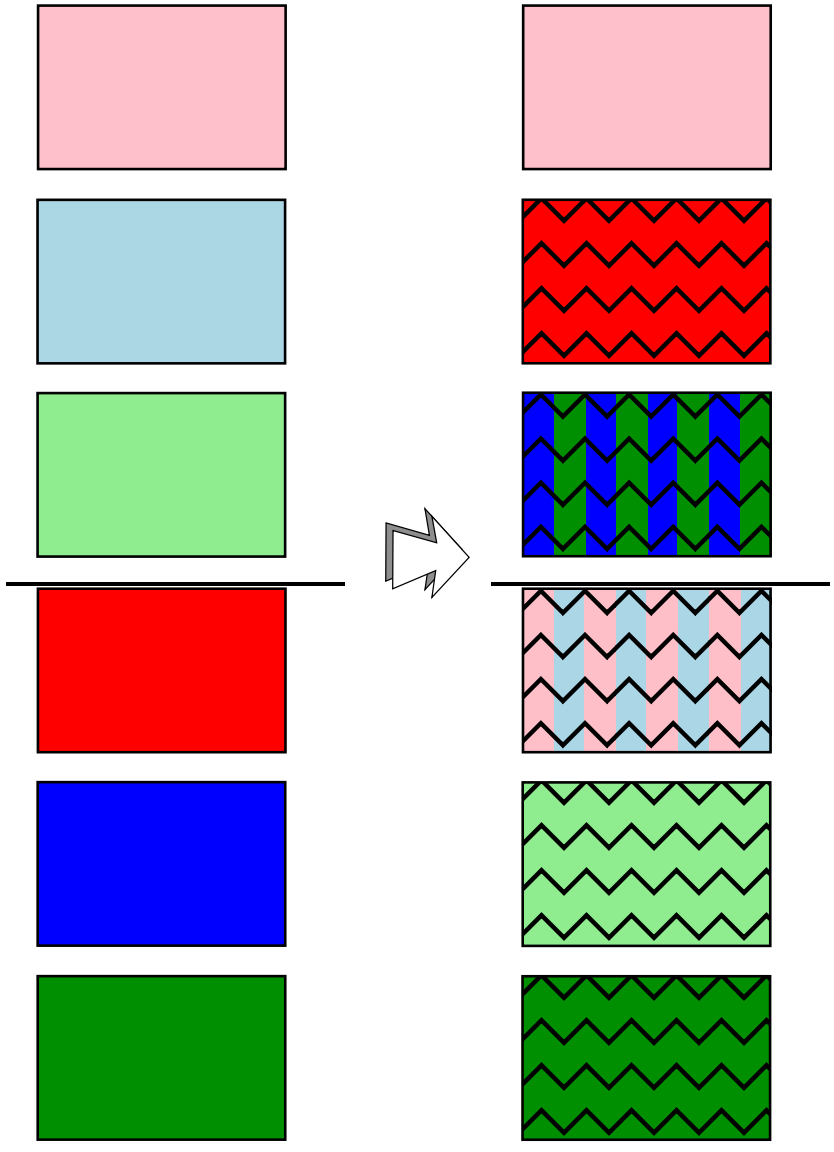
One step

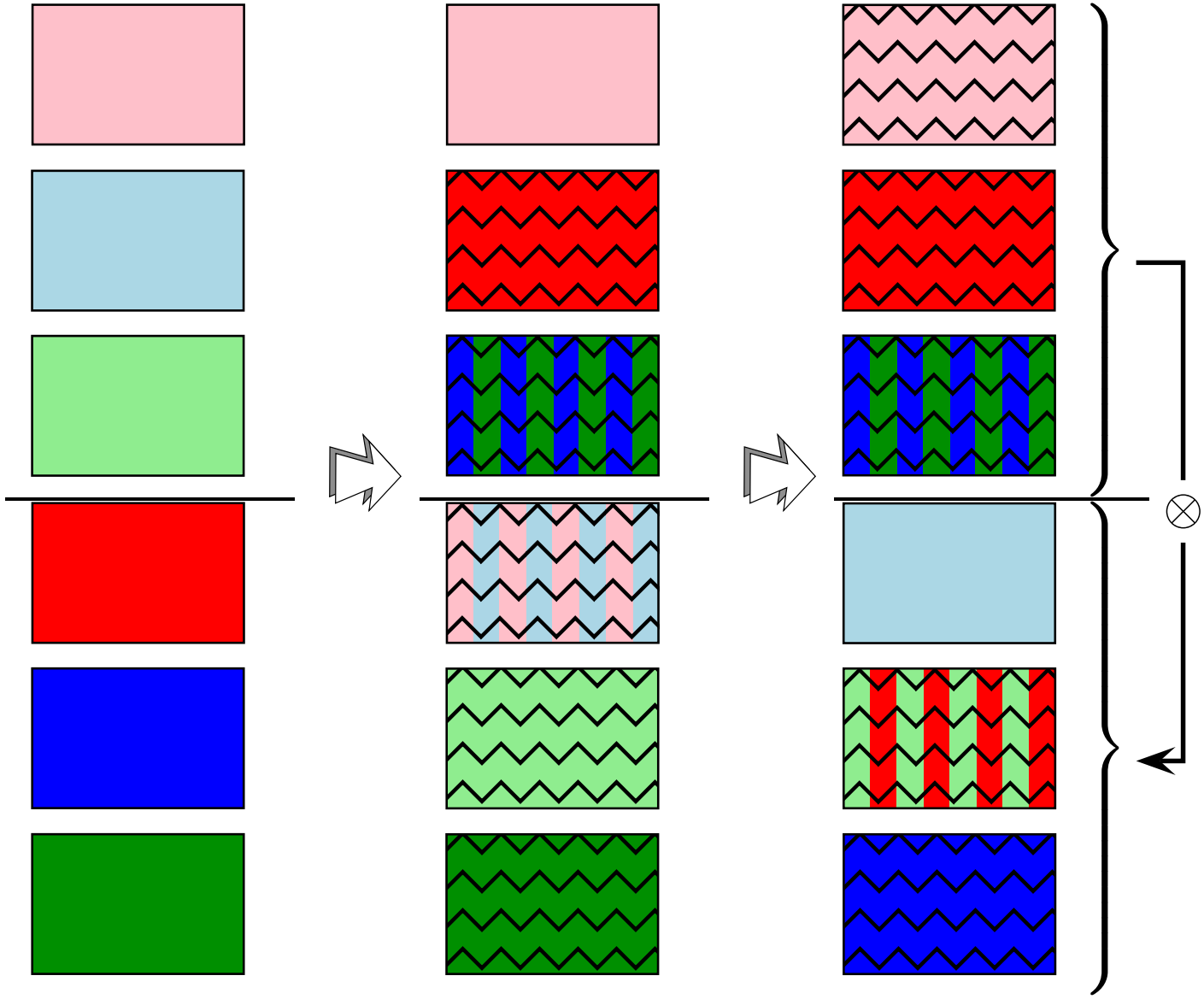


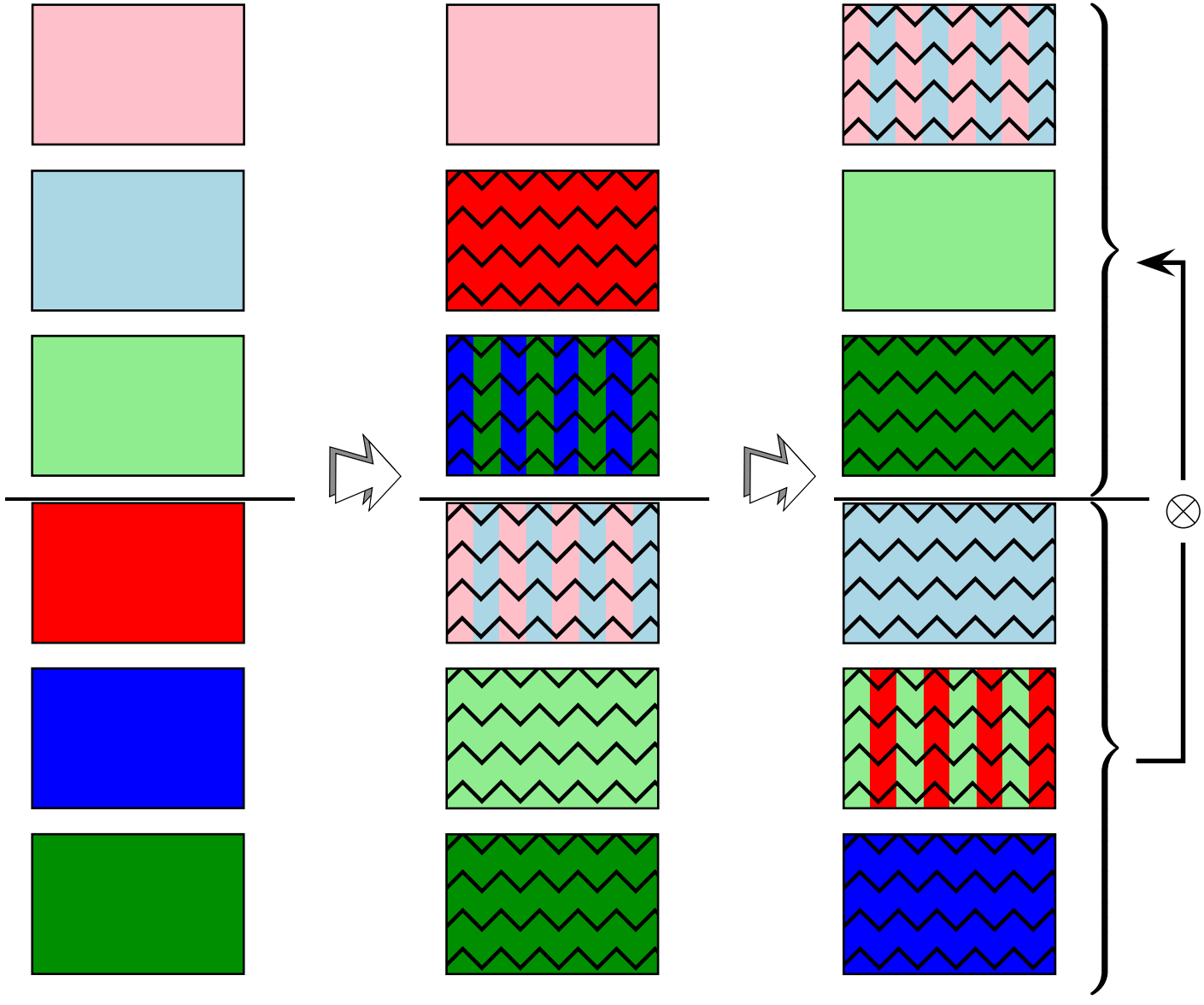
XOR!

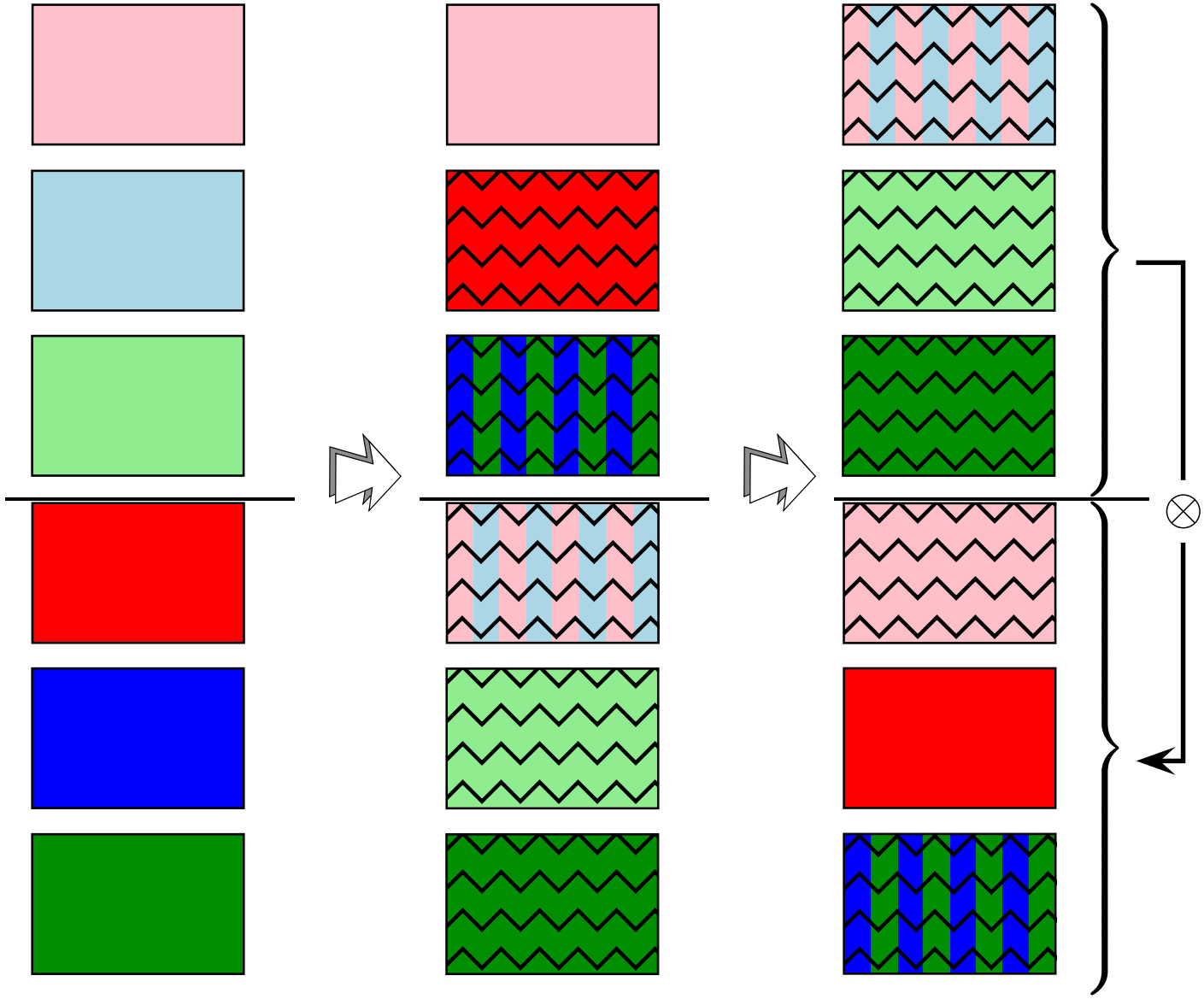


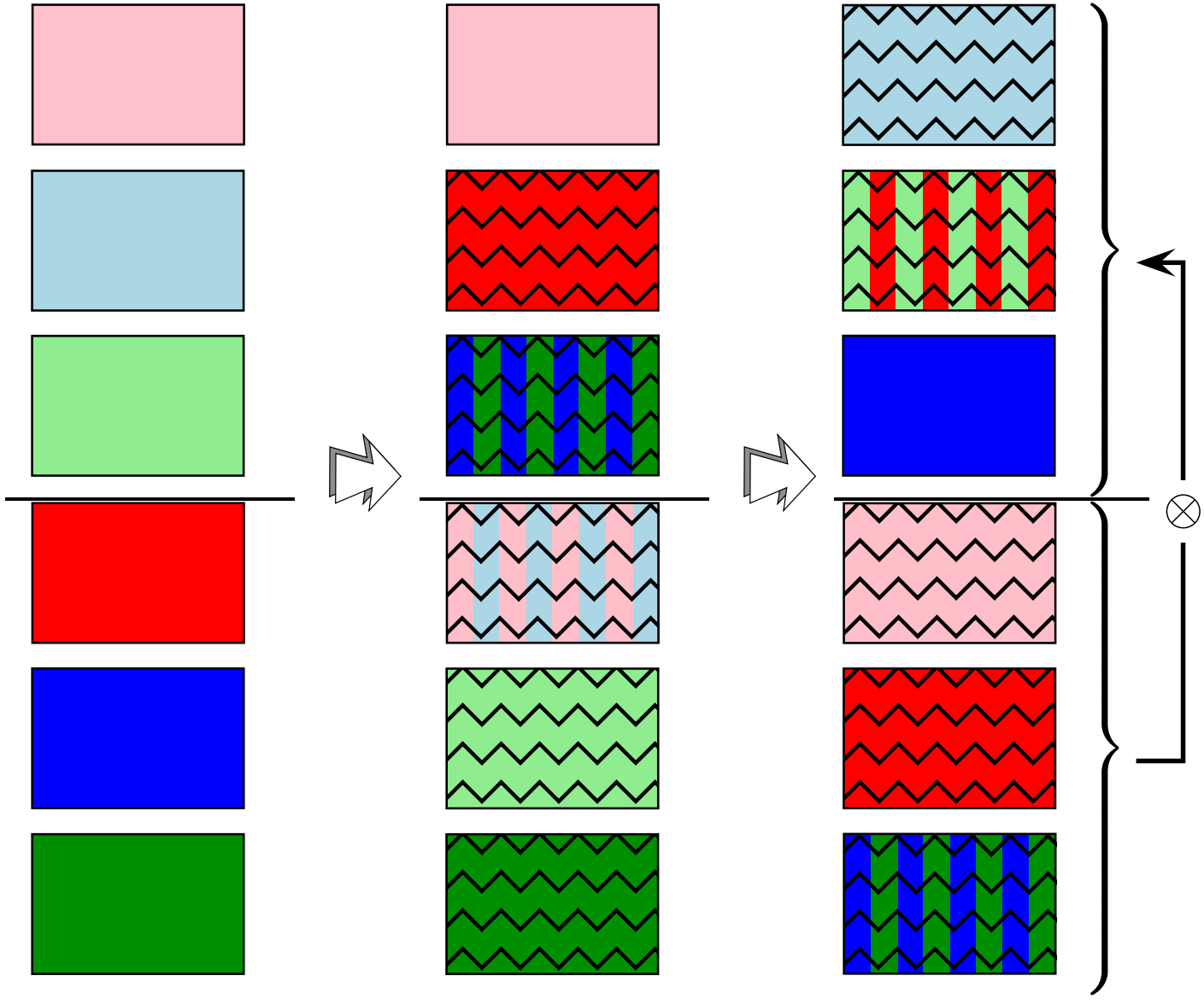


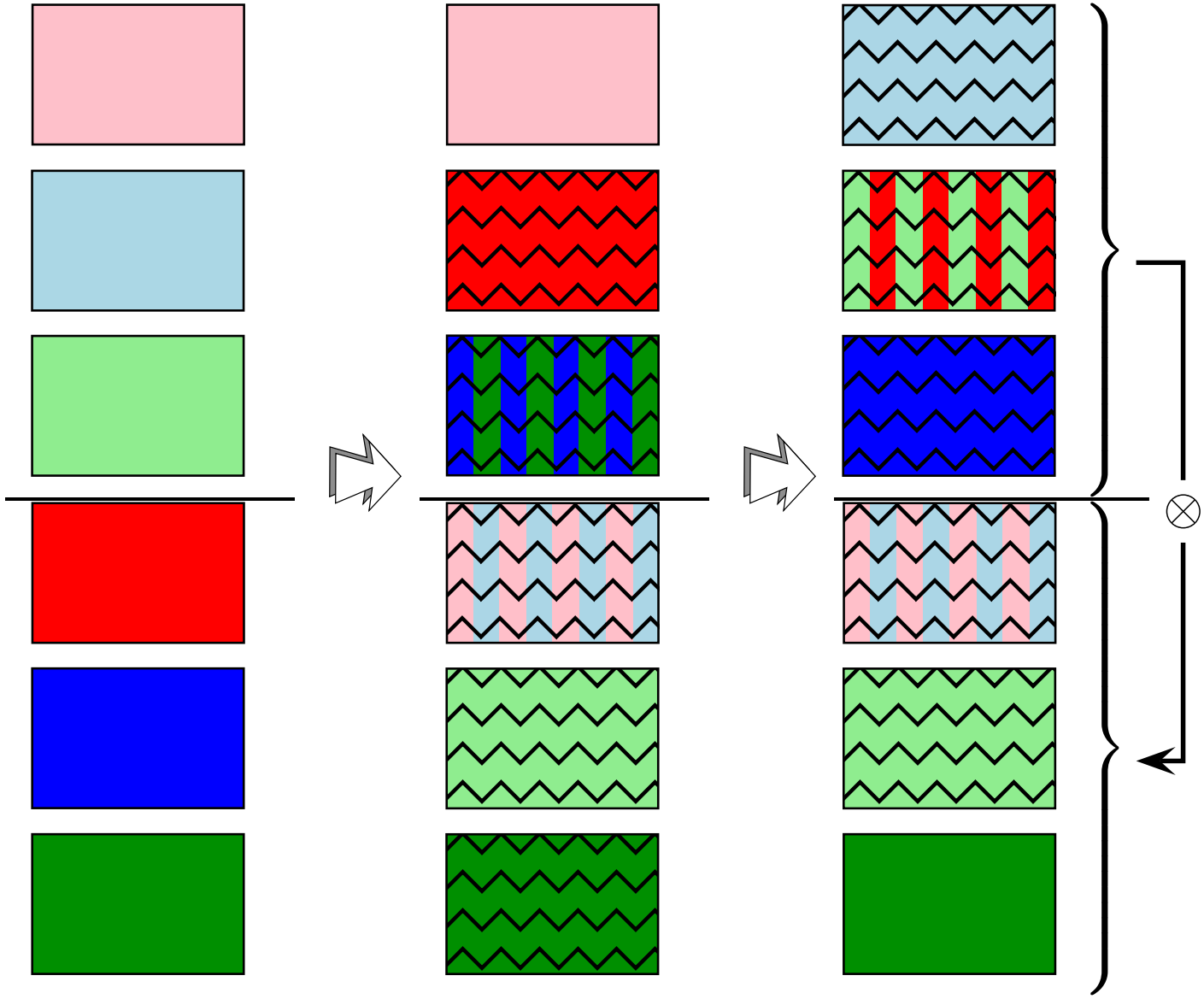


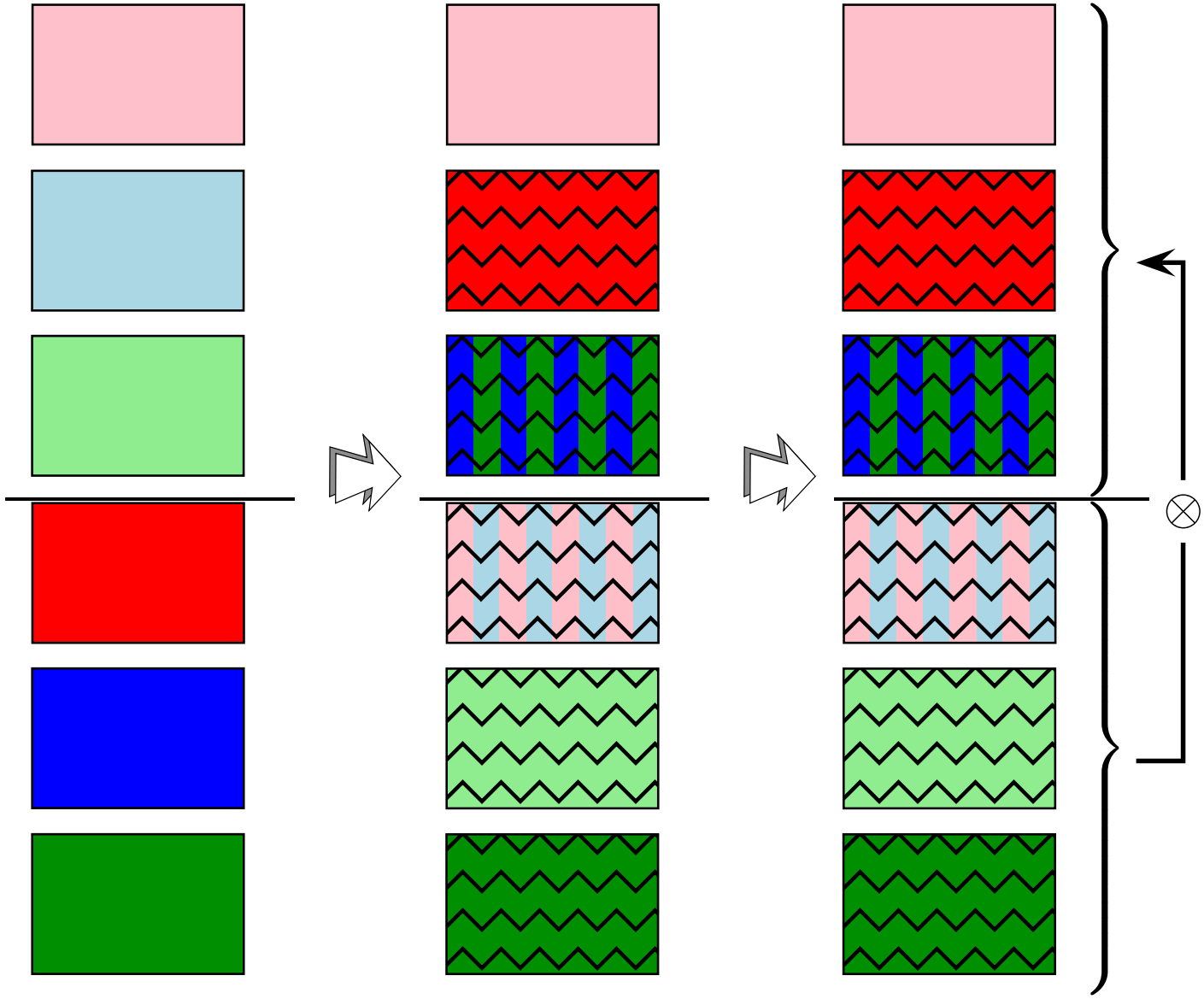




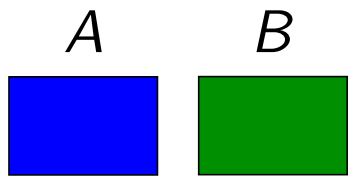








Why does this work?



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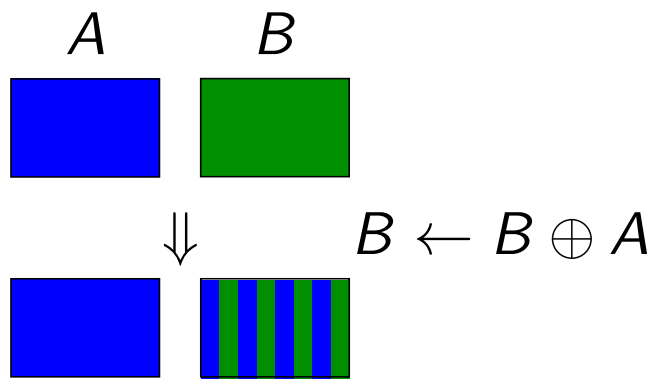

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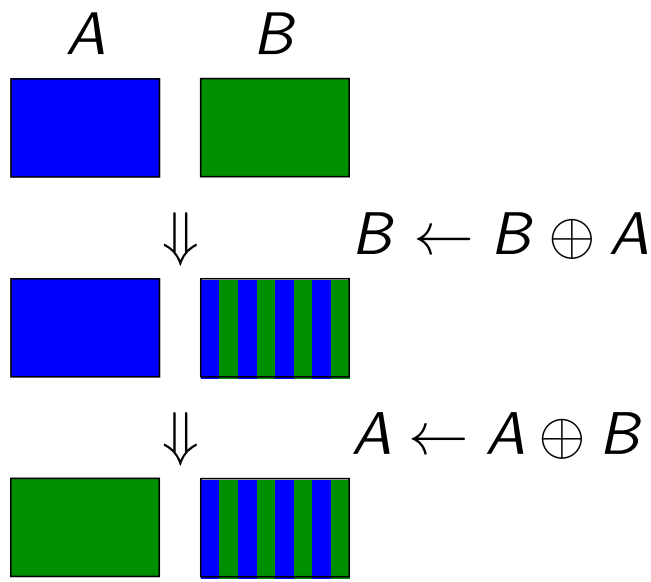

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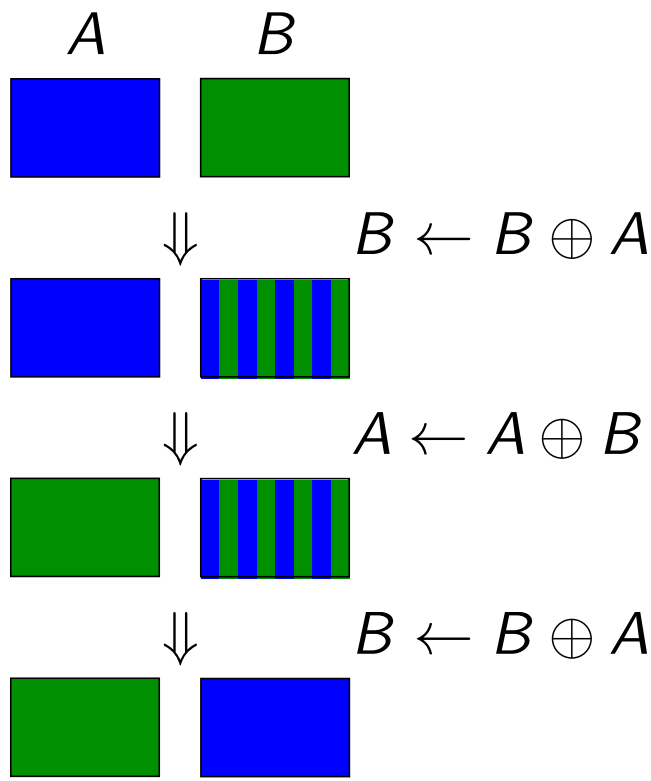

Runtime Encryption

Code as key material

- Encrypt the code to keep as little code as possible in the clear at any point in time during execution.

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- Extremes:
  1. Decrypt the next instruction, execute it, re-encrypt it, ... $\Rightarrow$ only one instruction is ever in the clear!
  2. Decrypt the entire program once, prior to execution, and leave it in cleartext. $\Rightarrow$ easy for the adversary to capture the code.

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- When the function returns you re-encrypt it.
- On entry, a function first encrypts its caller.
- Before returning, a function decrypts its caller.
- $\Rightarrow$ At most two functions are ever in the clear!

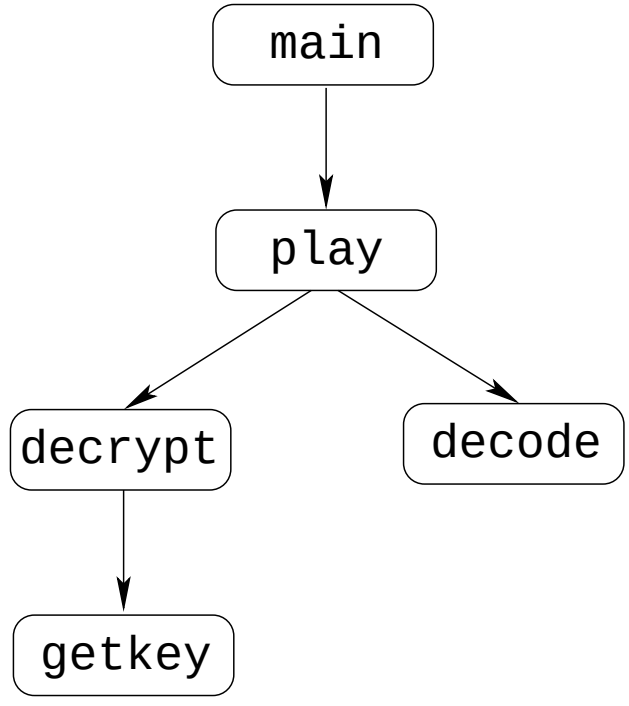
Code as key material

- What do we use as key? The code itself!

Code as key material

- What do we use as key? The code itself!
- What cipher do we use? Something simple!

- Simple case: tree-shaped call-graph:



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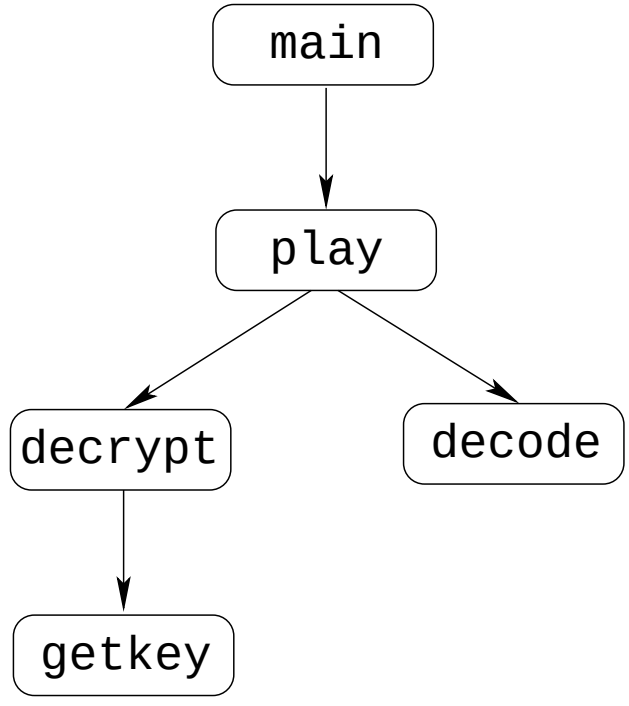

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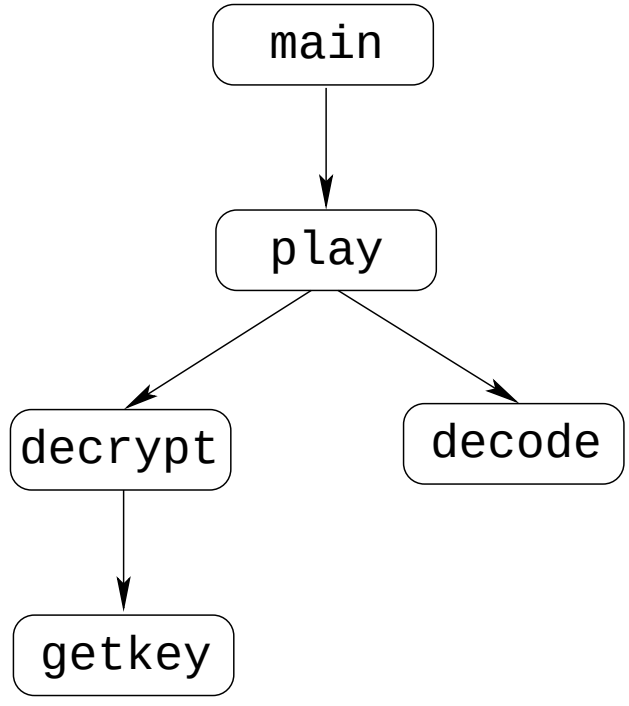

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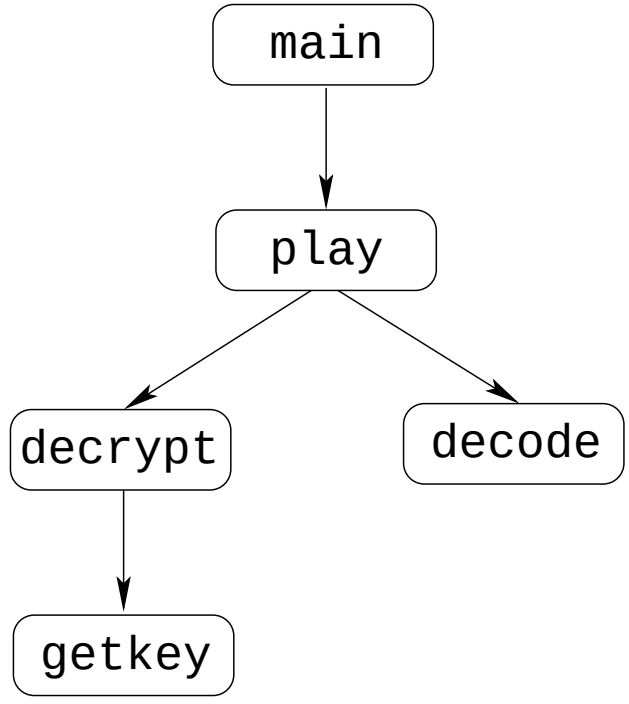

- Before/after procedure call: call guard function to decrypt/re-encrypt the callee.
- Entry/exit of the callee: encrypt/decrypt the caller.
- Key: Hash of the cleartext of the caller/callee.

```
int player_main (int argc, char *argv[]) {
    int user_key = 0xca7ca115;
    int digital_media[] = {10,102};
    guard(play,playSIZE,player_main,player_mainSIZE);
    play(user_key,digital_media,2);
    guard(play,playSIZE,player_main,player_mainSIZE);
}
int getkey(int user_key) {
    guard(decrypt,decryptSIZE,getkey,getkeySIZE);
    int player_key = 0xbabeca75;
    int v = user_key ^ player_key;
    guard(decrypt,decryptSIZE,getkey,getkeySIZE);
    return v;
}
int decrypt(int user_key, int media) {
    guard(play,playSIZE,decrypt,decryptSIZE);
    guard(getkey,getkeySIZE,decrypt,decryptSIZE);
    int key = getkey(user_key);
    guard(getkey,getkeySIZE,decrypt,decryptSIZE);
    int v = media ^ key;
    guard(play,playSIZE,decrypt,decryptSIZE);
    return v;
}
```

```
float decode (int digital) {
    guard(play,playSIZE,decode,decodeSIZE);
    float v = (float)digital;
    guard(play,playSIZE,decode,decodeSIZE);
    return v;
}
void play(int user_key, int digital_media[], int len) {
    int i;
    guard(player_main,player_mainSIZE,play,playSIZE);
    for(i=0;i<len;i++) {
        guard(decrypt,decryptSIZE,play,playSIZE);
        int digital = decrypt(user_key,digital_media[i]);
        guard(decrypt,decryptSIZE,play,playSIZE);

        guard(decode,decodeSIZE,play,playSIZE);
        printf("%f\n",decode(digital));
        guard(decode,decodeSIZE,play,playSIZE);
    }
    guard(player_main,player_mainSIZE,play,playSIZE);
}
```

```
void crypto (waddr_t proc,uint32 key,int words) {
    int i;
    for(i=1; i<words; i++) {
        *proc ^= key;
        proc++;
    }
}

void guard (waddr_t proc,int proc_words,
            waddr_t key_proc,int key_words) {
    uint32 key = hash1(key_proc,key_words);
    crypto(proc,key,proc_words);
}
```

Discussion

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- Code Privacy — make programs hard to understand to protect algorithms
- Data Privacy — make programs hard to understand to protect secret data (keys)

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- Prevent collusion — make every program unique to prevent diffing attacks
- Code Privacy — make programs hard to understand to protect algorithms
- Data Privacy — make programs hard to understand to protect secret data (keys)
- Integrity — make programs hard to understand to make them hard to change