Software Watermarking

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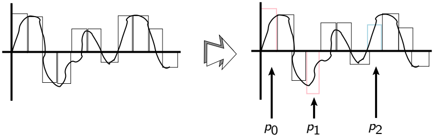
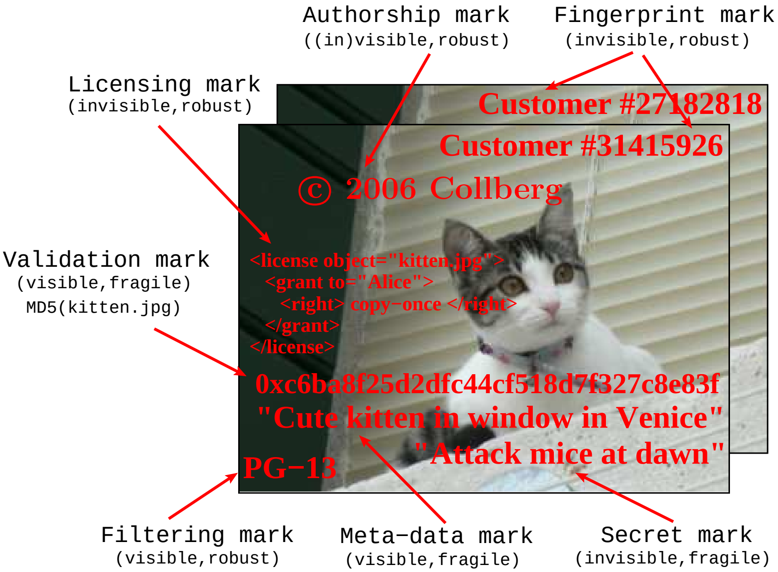
- *Software fingerprinting*: every copy you sell will have a different unique mark in it
- Trace the copy back to the original owner, and take legal action.

History and Applications

p. 468



History and Applications


Authorship mark
((in)visible,robust)
Fingerprint mark
(invisible,robust)
Licensing mark
(invisible,robust)
Customer #27182818
Customer #31415926
© 2006 Collberg
Validation mark
(visible,fragile)
MD5(kitten.jpg)
<license object="kitten.jpg">
<grant to="Alice">
<right> copy−once </right>
</grant>
</license>
0xc6ba8f25d2dfc44cf518d7f327c8e83f
"Cute kitten in window in Venice"
"Attack mice at dawn"
PG−13
Filtering mark
(visible,robust)
Meta−data mark
(visible,fragile)
Secret mark
(invisible,fragile)

Visible vs. invisible marks

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- A fragile mark could (and sometimes *should*) be easily destroyed by transformations to the cover object.
- Marks should survive lossy compression schemes, shrinking, cropping, xeroxing, PAL-to-NTSC,...

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- Example: Playboy's use of Digimarc.

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- Example: Beta copies of software.

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- Usage rules could be stored in file headers, but using watermarking ensures that the data remains even after transformations.

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- Example: captions.

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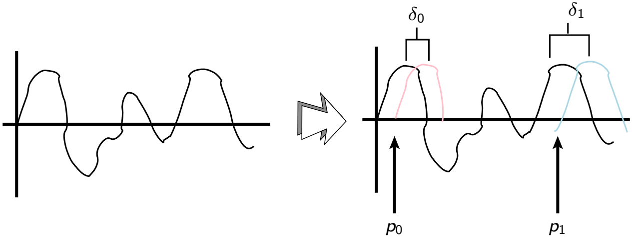
- Example:

> *Hidden in the X-rated pictures on several pornographic Web sites and the posted comments on sports chat rooms may lie the encrypted blueprints of the next terrorist attack against the United States or its allies.*

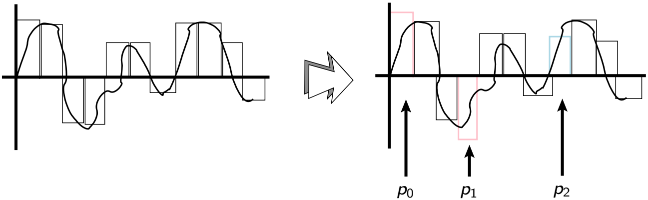
Audio marking: Echo hiding

- Embed echoes that are short enough to be imperceptible to the human ear:



Audio: Least Significant Bit

- LSB of an audio sample is the one that contributes least to your perception,



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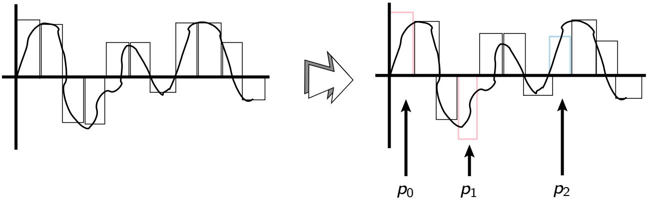


Audio: Least Significant Bit

- LSB of an audio sample is the one that contributes least to your perception,
- Alter without adversely affecting quality!
- *Attack*: randomly replace the least significant bit of every sample!

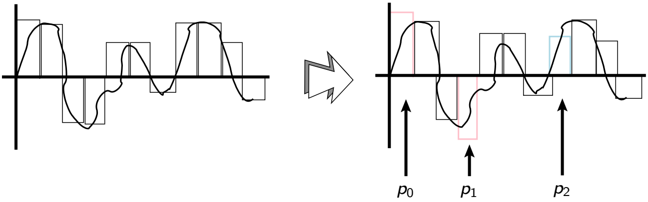
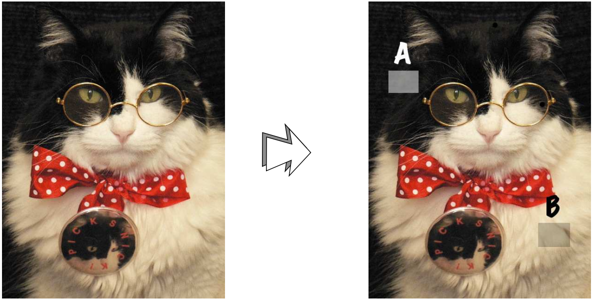


Image: Patchwork

- Embed a single bit by manipulating the brightness of pixels.



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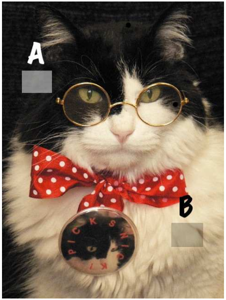
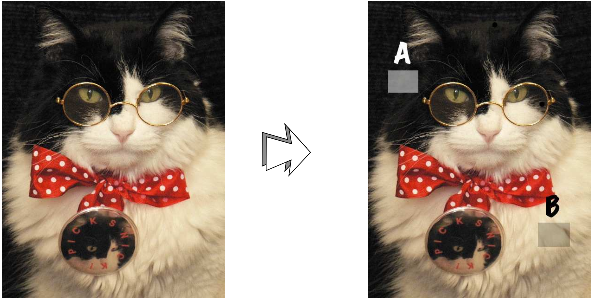


Image: Patchwork

- Embed a single bit by manipulating the brightness of pixels.
- Use a pseudo-random number sequence to trace out pairs (A, B) of pixels
- During embedding adjust the brightness of A up by a small amount, and B down by the same small amount:



Patchwork: Embedding algorithm

EMBED(P, key):

1. `Init_RND(key);` $\delta \leftarrow 5$
2. $i \leftarrow$ `RND()`; $j \leftarrow$ `RND()`
3. Adjust the brightness of pixels a_i and b_i: $a_i \leftarrow a_i + \delta$; $b_j \leftarrow b_j - \delta$
4. repeat from 2 ≈ 10000 times □

Patchwork: Recognition algorithm

RECOGNIZE(P, *key*):

1. `Init_RND(`*key*`);` $S \leftarrow 0$
2. $i \leftarrow$ `RND()`; $j \leftarrow$ `RND()`
3. $S \leftarrow S + (a_i - b_j)$
4. repeat from 2 ≈ 10000 times
5. if $S \gg 0 \Rightarrow 0$ output `"marked!"` □

Blind vs. Informed

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Blind vs. Informed

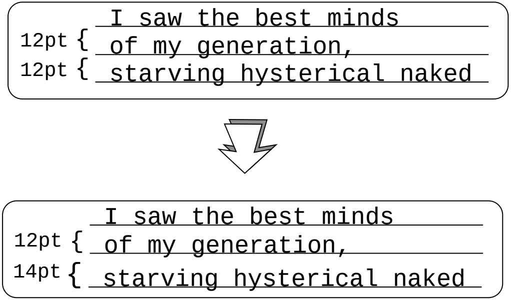
- Watermarking recognizers are either *blind* or *informed*.
- To extract a blind mark you need the marked object and the secret key.
- To extract an informed mark you need extra information, such as original, unwatermarked, object.

Watermarking text

- Cover object types:
    - the text itself with formatting (ASCII text); or
    - free-flowing text;
    - an *image* of the text (PostScript or PDF).

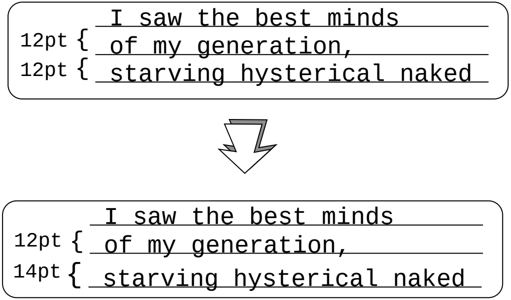
Watermarking Text: PDF

- Similar to marking images.



Watermarking Text: PDF

- Similar to marking images.
- Example: encode 0-bit or a 1-bit by hanging word/line spacing.



Watermarking Text: formatted ASCII

- Encode the mark in white-space: 1 space = 0-bit, 2 spaces = 1-bit:

```
I␣saw␣the␣best␣minds
of␣my␣generation,
starving␣hysterical␣naked
```

```
I␣␣␣saw␣␣the␣best␣␣␣minds
of␣␣␣␣␣␣␣my␣␣␣generation,
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```

Watermarking Text: Synonym replacement

- Replace words with synonyms.
- Insert spelling or punctuation errors.

```
I saw the best minds
of my generation,
starving hysterical naked
```

```
I observed the choice intellects
of my generation,
famished hysterical nude
```

Watermarking Text: Syntax

- Encode a mark in the syntactic structure of an English text:
    1. Devise an extract function which computes a bit from a sentence,
    2. Modify the sentence until it embeds the *right* bit.

```
I saw the best minds
of my generation,
starving hysterical naked
```

```
It was the best minds
of my generation that I saw,
starving hysterical naked
```

Watermarking Text: Atallah et al.

1. Chunk up the watermark, embed one piece per sentence.
2. A function computes one bit per syntax tree node.
3. Modify sentence until these bits embed a watermark chunk.
4. A *marker* sentence precedes every watermark-bearing sentence.

```
I saw the best minds
of my generation,
starving hysterical naked
```

```
I saw the best minds of my
generation. They were starving
hysterical naked. None, baby,
none were smarter than them. Nor
more lacking in supply of essential
nutrients or in more need of
adequate clothing. Baby.
```

Watermarking Software

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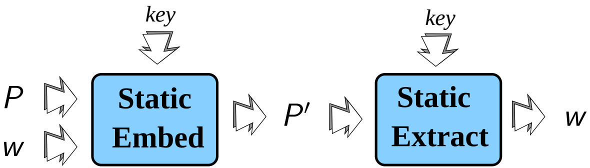
Static watermarks



You care about

- Encoding bitrate
- Stealth
- Resilience to attack

Ideas for Software Watermark Algorithms

Encode the watermark

- in a permutation of a language structure

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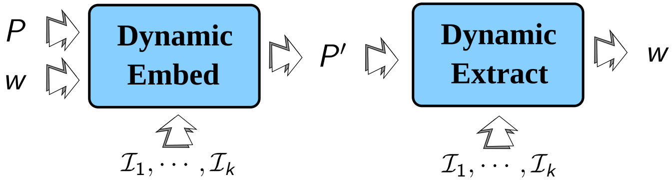
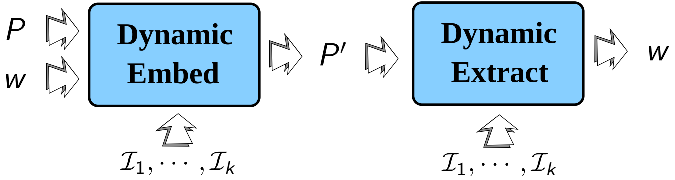
- as a solution to a static analysis problem
- in the topology of a CFG

Dynamic watermarks



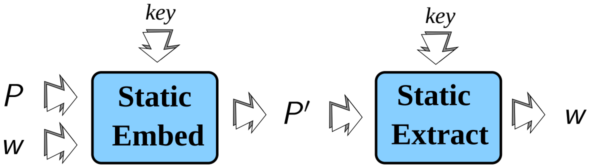
- Encode the watermark in the runtime state of the program

Dynamic watermarks



- Encode the watermark in the runtime state of the program
- Dynamic marks appear more robust, but are more cumbersome to use

Attacks against software watermarks



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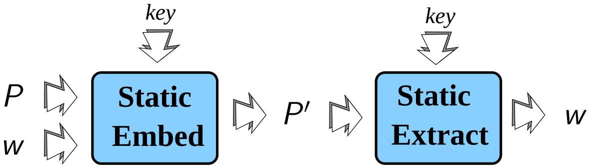

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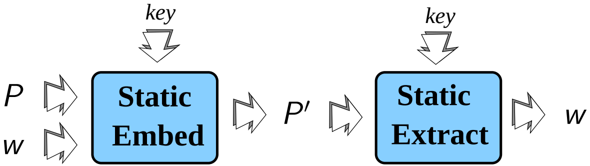

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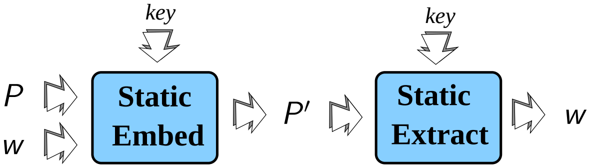

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- The adversary has complete access to the program
- The adversary doesn't know the key
- The adversary doesn't know the embedding location (it's key dependent)

Attacks — Rewrite attack

- Alice has to assume that Bob will try to destroy her marks before trying to resell the program!
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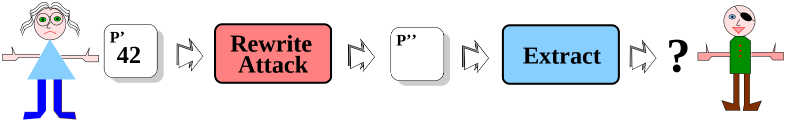
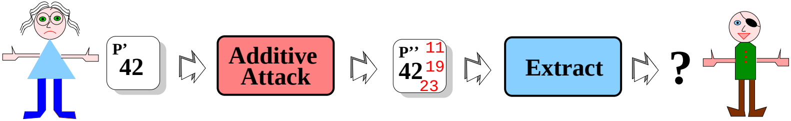


- Ideally, this is the *only* effective attack.

Attacks — Additive attack

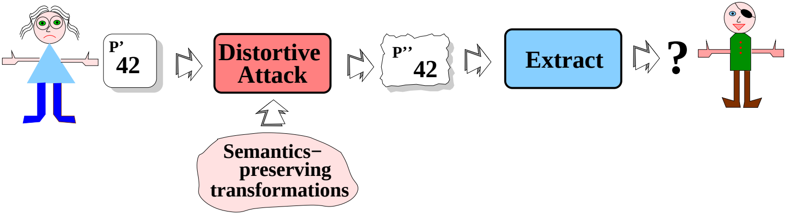
- Bob can also add his own watermarks to the program:



- An additive attack can help Bob to cast doubt in court as to whose watermark is the original one.

Attacks — Distortive attack

- A distortive attack applies semantics-preserving transformations to try to disturb Alice's recognizer:



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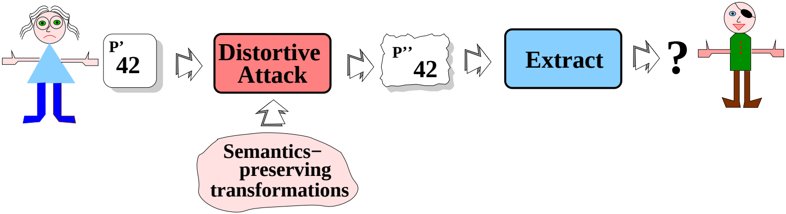

- Transformations: code optimizations, obfuscations,...

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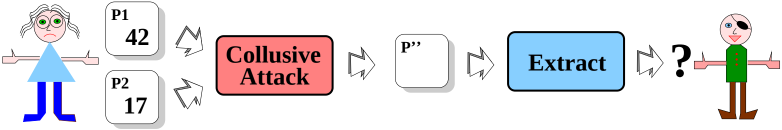
- Bob buys two differently marked copies and comparing them to discover the location of the fingerprint:



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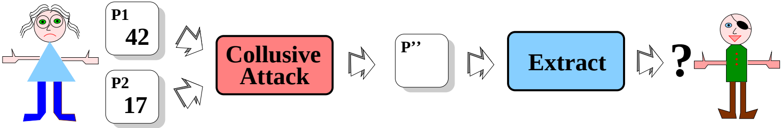

- Alice should apply a different set of obfuscations to each distributed copy, so that comparing two copies of the same program will yield little information.

Watermarking Algorithms

Watermarking by Permutation

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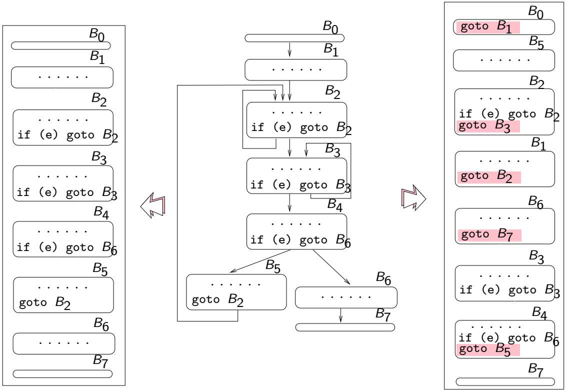
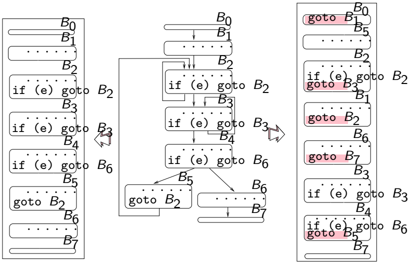


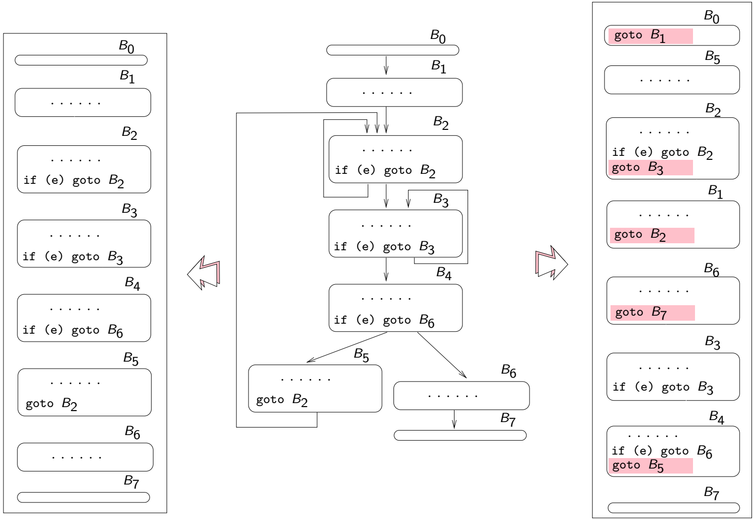
Algorithm WMDM

p. 488

Reordering Basic Blocks



Algorithm WMDM: Reordering Basic Blocks



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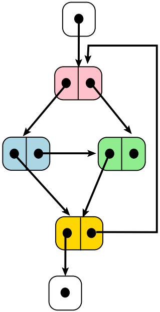
  watermarking bits.
- What about stealth?

Algorithm WMVVS

p. 506

Watermarks in CFGs



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  2. Tie the CFG tightly to the rest of the program.
- Issues:
  1. How do you encode a number in a CFG?
  2. How do you find the watermark CFG?
  3. How do you attach the watermark CFG to the rest of the program?

Algorithm WMVVS: Embedding

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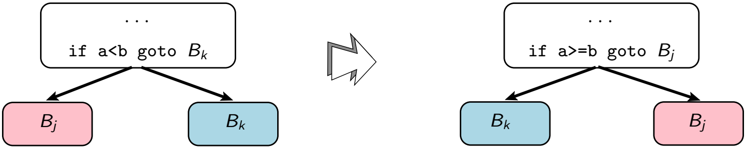

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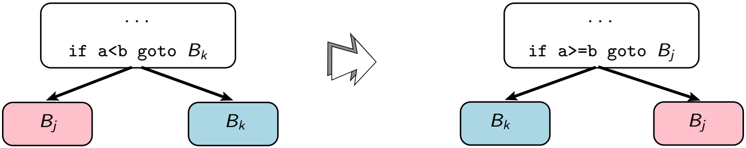
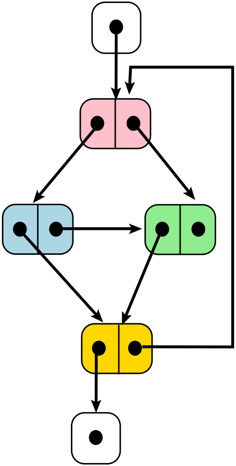


- Reducible Permutation Graphs (RPGs)



```
public static int bogus;
public static int m4(int i) {
    i = i & 0x7BFF;
    bogus+=2; i-=i>>2;
    do {
        i = i >> 3;
        label: {
            if (++bogus <= 0) {
                i = i | 0x1000;
                if ((bogus += 6) == 0)
                    break label;
            }
            ++bogus;
            i = i * 88 >>> 1;
        }
        i = i | 0x4;
    } while((bogus += 6)<0);
    bogus+=2; return i;
}
```

```
public void P(boolean S) {
   if (S)
      System.out.println("YES");
   else
      System.out.println("NO");
}

public void main (String args[]) {
   for (int i=1; i<args.length; i++) {
      if (args[0].equals(args[i])) {
         P(true);
         if (m4(3)<0)
         P(false);
         return;
      }
   }
   m3(-1);
   P(false);
}
```

```
public int bogus;
public int m4(int i) {
   i = i & 0x7BFF;
   bogus += 2;
   i -= i >> 2;
   do {
      if (i<-6)
         P(bogus<i);
      i = i >> 3;
      label: {
         if (++bogus <= 0) {
            i = i | 0x1000;
            m3(0);
            if ((bogus+=6)==0)
               break label;
         }
         ++bogus;
         i = i * 88 >>> 1;
      }
      i = i | 0x4;
   } while (((bogus += 6)<0)
            && (m3(9)>=0) )
   bogus += 2;
   return i;
}
```

```
public int m3(int i) {
   i = i ^ i >> 0x1F;
   i = i / 4 * 3;
   do {
      i -= i >> 3;
      if((bogus += 11) <= 0)
         break;
```

Algorithm WMVVS: Recognition

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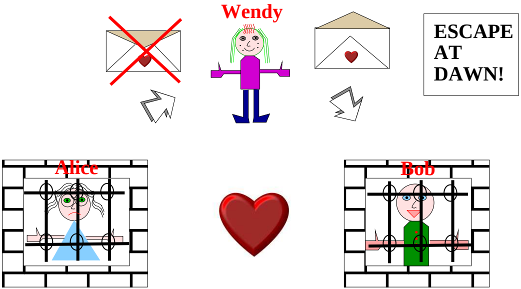
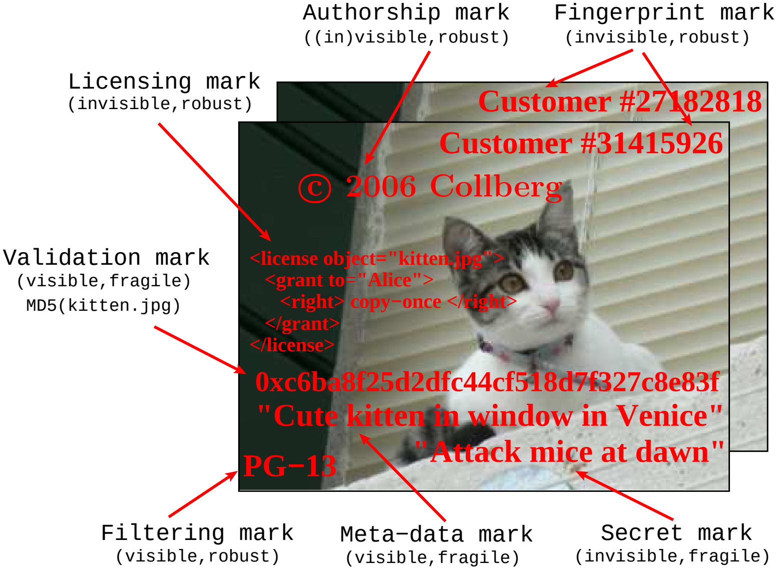
- The embedder can split the watermarking into pieces, for higher bitrate.

Steganographic Embeddings

p. 522



Steganographic Embeddings



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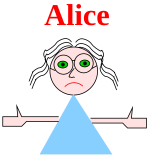
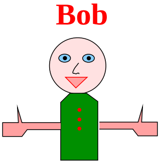
Steganography — Prisoners' Problem





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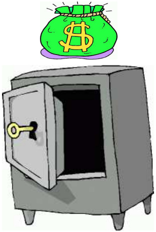

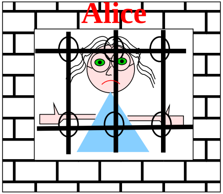

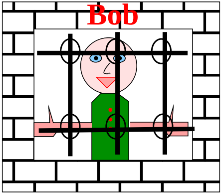

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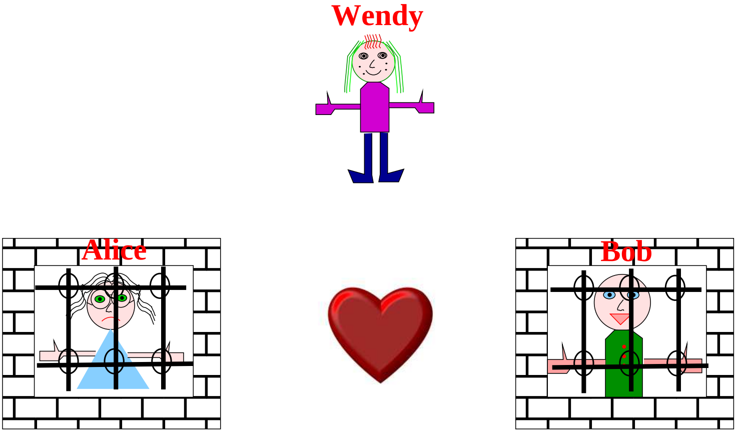

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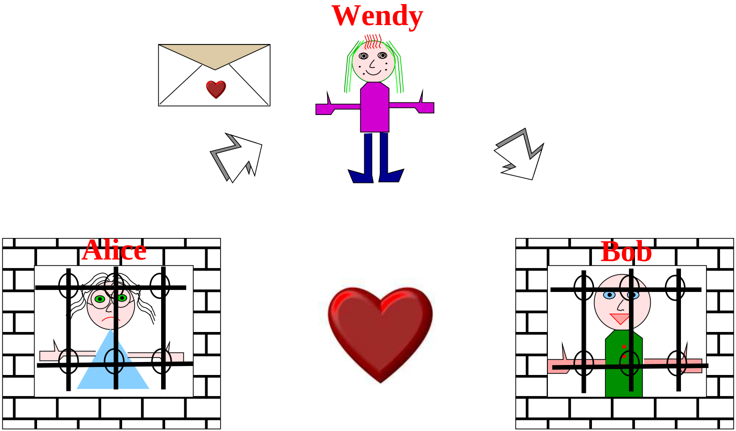

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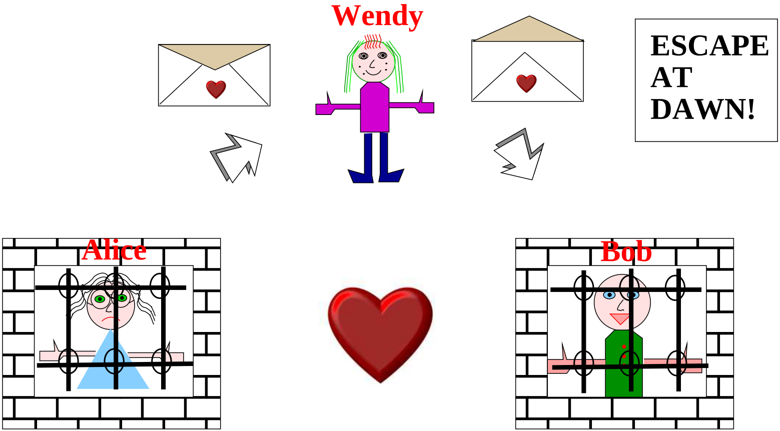

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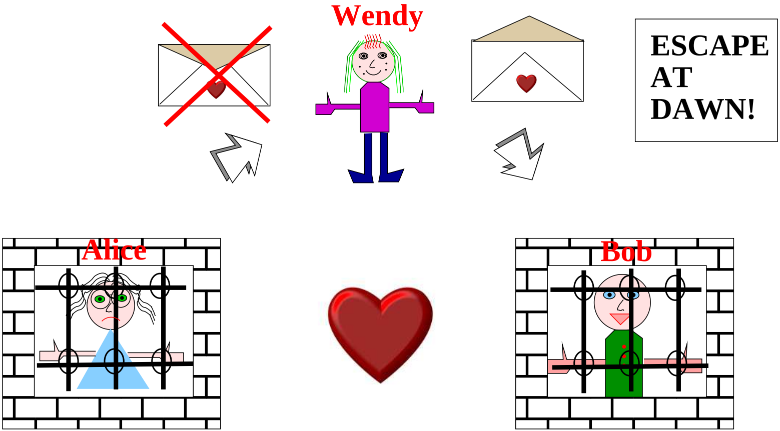


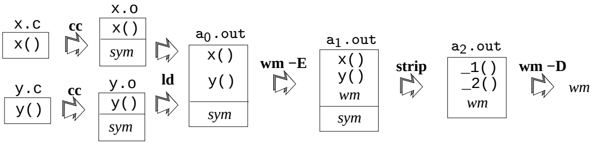
Steganography — Null cipher

```
Easter is soon, dear! So many flowers! Can you
smell them? Are you cold at night? Prison food
stinks! Eat well, still! Are you lonely? The
prison cat is cute! Don't worry! All is well!
Wendy is nice! Need you! ):
```

Algorithm wmASB

p. 523

Hidden Messages in x86 Binaries



WMASB: Hidden Messages in x86 Binaries

- Basic idea: Play compiler!

  whenever the compiler has a choice in which code to generate, or the order in which to generate it, pick the choice that embeds the next bits from the message W*.*

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   1. codebook $\mathcal{B}$ of equivalent instruction sequences

`mul` r_i,x,5
`shl` r_i,x,2 `add` r_i,r_i,x
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2. Encrypt W with *key*.
3. Canonicalize P:
   1. Sort block chains, procedures, modules
   2. Order instructions in each block in standard order
   3. Replace each instruction with the first alternative from $\mathcal{B}$.

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   Use $\mathcal{M}$ to avoid picking unusual schedules.
6. Instruction selection: Use $\mathcal{B}$ to embed bits from W by replacing instructions. Use $\mathcal{M}$ to avoid unusual instruction sequences.

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- Instruction selection:
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- Code layout:
  - Compilers lay out code for locality: don't deviate too much from that!

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- Real code doesn't use unusual instruction sequences.
- Real code contains many schedules for the same dependency graph

Wanna design a watermarking algorithm?

- Find a language structure into which to encode the mark (CFGs, threads, dynamic control flow. . .)

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- Decide on an attack model.

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