Data Compression and IoT

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Outline

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What is data compression?

Definition (Data compression)

Representation of information using less space than original data. The action to compress data is called **compression** and the opposite actions is called **decompression**. It's a particular case of encoding/decoding information.

- Kinds of compression:
  - Loseless
  - Lossy

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Loseless compression

- Information can be retrieved exactly as original data.
- Usually used for text compression
- Some known formats:
  - Zip
  - GZip
  - RAR
  - ACE
  - 7Zip
  - B2Zip
  - ...

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Lossy compression

- Information loses some data, that cannot be retrieved exactly as before it is compressed.
- Usually used for media compression: images, audio, video.
- Some known formats:
  - JPEG, GIF, PNG, ...
  - MP3, OGG, AAC, ...
  - H264, MPEG-4, VP8, ...

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Kinds of information

- **Redundant**
  - Repetitive data
  - Predictable data
- **Irrelevant**
  - Invisible data
  - Removing this data don't affect message content
- **Basic**
  - Essential data
  - It's needed to retrieve original data
  - It should be transmitted

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Lets see an example: Fruit 100% random & $\mathfrak{I}(\mathfrak{country})$

There are six popular fruits in an imaginary random country with some states (about 32). People in the country implements an elections system to know: What's the favorite fruit ever in this random, imaginary and 100% hypothetical country?

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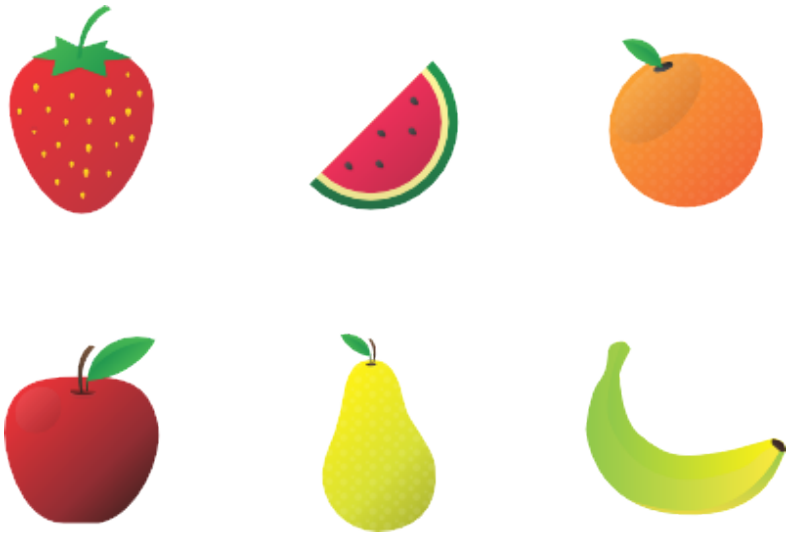

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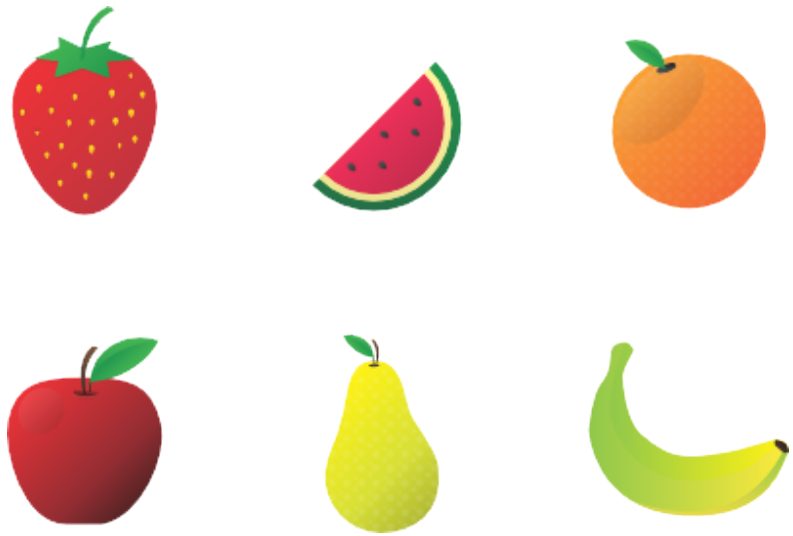

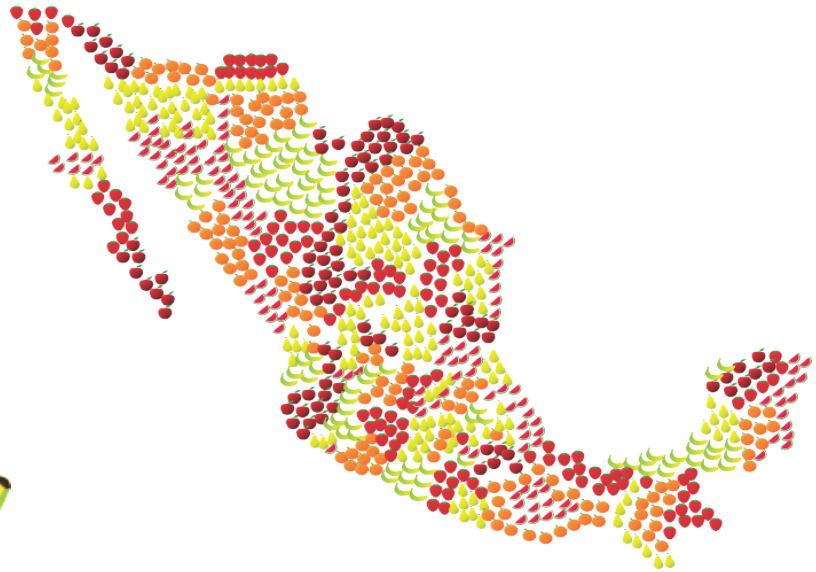

Can you see the different kinds of information?

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Fruit 100% random & $\mathfrak{I}(\mathtt{country})$: Game rules

The election system has following rules:

- Each citizen has an unique ID scanned from his/her ID card.
- Each citizen can vote only once and only by one fruit.
- If somebody tries to vote twice or more, then all votes from this citizen will be invalidated.
- Any citizen can vote in any state.
- There is a central system publishing partial live results.
- Each state has a system to votes counting and this reports to the central system. This systems only can report (to central system) votes from citizens who are natives from that state.
- In anytime the systems in each states can communicate with the other state systems to report votes from non-native citizens.

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Logistics (brainstorming)

- How people can vote?
- Is an app needed?
- How people can vote outside of their state? (non-native people)
- Infrastructure?

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Architecture and design (brainstorming)

- First, think in the small case (i.e. one server by state)
- Solve for this case
- Improve to solve big case (i.e. dividing each states by districts)

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What about data transferring? (brainstorming)

Do you have some ideas for the system?

- One vote once?
- Several votes at once?
- What technology can we use?
  - XML
  - JSON
  - Our own coding method?

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Data transferring: XML? (brainstorming)

```
1  <?xml version="1.0" encoding="UTF-8" ?>
2  <!DOCTYPE FruitCountry SYSTEM "votes.dtd">
3  <state id="25">
4      <vote>
5          <citizen id="111999" />
6          <by>Apple</by>
7      </vote>
8       ...
9      <vote>
10         <citizen id="333777" />
11         <by>Strawberry</by>
12     </vote>
13 </state>
```

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Data transferring: JSON? (brainstorming)

```
{
    state: 25,
    votes: [
        { citizen: 111999, by: 'Apple' },
        { citizen: 222888, by: 'Pear' },
        { citizen: 222888, by: 'Banana' },
        { citizen: 222888, by: 'Watermelon' },
        ...
        { citizen: 333777, by: 'Strawberry' }
        { citizen: 333777, by: 'Orange' }
    ]
}
```

Data transferring: Our own coding method? (brainstorming)

- What if we use some abreviations?
  - A: Apple
  - B: Banana
  - O: Orange
  - P: Pear
  - S: Strawberry
  - W: Watermelon
- Do we really need to send the citizen ID?
- Do we really need to send the state ID?
- Fixed width messages?
- A possible message from state to central system:

25 AAAAPPPPPBBBBBWWWSSOOOOOAAA

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Run-Length Encoding (basic idea)

RLE Algorithm

The idea is counting the times that each character appears consecutively. For example, for a string:

$$S = \mathtt{aaaabbbbbbbbbaaaaaabbbbbbbccccccbb}$$

its compressed representation will be:

$$\tilde{S} = \mathtt{a4b8a5b6c5b2}$$

Run-Length Encoding (algorithm v1.0)

```
function char * compress(const char *input)begin
    char *str ← input;
    char *output ← new char;
    int length ← 0;
    while *str ≠ 0 do
        char x ← *str;
        push-back(output,x);
        int k ← 1;
        while x = *(++str) do k++;
        push-back(output,to-alpha(k));
        length ← length+k+1;
    end
    return strlen(output) < length ? output : input;
end
```

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Run-Length Encoding (inconvenients)

- What about decompression?

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- Maybe, original string was like:

$$S = aaa11111bbbb$$

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- Maybe, original string was like:

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- Or maybe was:

$$S = aaa \cdots aaabbbb$$

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Run-Length Encoding (inconvenients)

- What about decompression? Very simple, duh!
- What happens if we got a compressed (and ambiguos) string like following?

$$\tilde{S} = a3\mathbf{15}b3$$

- Maybe, original string was like:

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$$S = aaa \cdots aaabbbb$$

- Is this algorithm effective with XML or JSON?

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$$S = "e><v" = \quad 00100101 \quad 00111110 \quad 00111100 \quad 01110110$$
$$\tilde{S} = 010001010001001001010101011100011011001010001$$

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$$S = "e><v" = \begin{array}{cccc} 00100101 & 00111110 & 00111100 & 01110110 \end{array}$$
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FAIL!!

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FAIL!!

- What if we limit the repetitions? (i.e. MAX 9 repetitions)

$$S = aaaaaaaaaaaabbb$$
$$\tilde{S} = a9a3b3$$

Run-Length Encoding (improved v2.0)

- What if the number of repetitions always are represented by only one byte?

- What is the maximum repetition for a single character in this representation?
- How can detect corrupted data from compressed message?

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$$\tilde{S} = a!b\#$$

This compressed string represents 33 a's followed by 35 b's. Why?

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This compressed string represents 33 a's followed by 35 b's. Why?

  - The ASCII code of ! is 33 and the code of $\#$ is 35. Then, in this representation the $2k$-th characters are basic information and $(2k+1)$-th characters are number of repetitions, where $k = 0, 1, 2, \ldots, \frac{n}{2}$.
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Run-Length Encoding (improved v2.0)

```
function char * compress(const char *input)begin
    const char MAX ← ~0;
    char *str ← input;
    char *output ← new char;
    int length ← 0;
    while *str ≠ 0 do
        char x ← *str;
        push-back(output,x);
        char k ← 1;
        while x = *(++str) && k < MAX do k++;
        push-back(output,k);
        length ← length+k+1;
    end
    return strlen(output) < length ? output : input;
end
```

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Run-Length Encoding (decompression)

```
function char * decompress(const char *input)begin
    char *c ← input;
    char *output ← new char;
    while *c ≠ 0 do
        char n ← *(c+1);
        for i = 1 to n do push-back(output,*c) ;
        c ← c+2;
    end
    return output;
end
```

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Run-Length Encoding (improved v3.0)

Maybe we can do better:

- We can analize input message to see what unique characters are contained in the mesage.
- Then, we can construct a reduced alphabet. For example, $\Sigma = \{A, B, O, P, S, W\}$.
- In this case only need 3 bits to represent characters.
- We can use 5 bits to store repetitions (so, we will have MAX 31 repetitions by character).

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Run-Length Encoding (improved v4.0 PRO)

Moreover, what happens if we can detect whole words?

$$S = \mathrm{abcdabcdabcdbdbdbdbd}$$

$$\tilde{S} = [\mathrm{abcd}]\,3\,[\mathrm{bd}]\,4$$

Outline

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Probability basics

Experiments and Events

An event is a set of posible results in an experiment execution. For example, taking a card from a deck or rolling a dice. We can denote all posible results with Ω and an event with uppercase letter such that $A \subseteq \Omega$ or $A \in 2^{\Omega}$, then A is a subset of Ω.

Probability

Is an indicator that describes the frecuency of an event in one universal set of posibilities. Daily, we express that indicator as a percentage value or value between 0 and 1. Then we can define the probability as:

$$p : 2^{\Omega} \mapsto [0, 1]$$

Probability basics

- So, when Ω is a discrete and finite set, then:

$$\mathrm{p}(A) = \frac{\#A}{\#\Omega}$$

- We name this as uniform distribution or counting distribution.
- However, counting elements in A and Ω isn't always trivial. Maybe we need to use operations like factorial, combinations, permutations, etcetera.

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Probability basics

- Key pressing random letter of the english keyboard such that the letter be a vowel.
  - Let $A = \{a, e, i, o, u\}$ and $\Omega = \{a, ..., z\}$,then $p(A) = \frac{5}{26}$.
- Rolling a dice such that the result be greater than 2.
  - Let $A = \{3, 4, 5, 6\}$ and $\Omega = \{1, 2, 3, 4, 5, 6\}$,then $p(A) = \frac{2}{3}$.,
- Taking a card from a deck such that getting a red card.
  - Let $A = \{A\heartsuit, 2\heartsuit, ..., 10\heartsuit, J\heartsuit, Q\heartsuit, K\heartsuit, A\diamondsuit, 2\diamondsuit, ..., 10\diamondsuit, J\diamondsuit, Q\diamondsuit, K\diamondsuit\}$ and $\Omega = \left\{ \begin{array}{ll} A\heartsuit, 2\heartsuit, ..., 10\heartsuit, J\heartsuit, Q\heartsuit, K\heartsuit, & A\diamondsuit, 2\diamondsuit, ..., 10\diamondsuit, J\diamondsuit, Q\diamondsuit, K\diamondsuit, \\ A\spadesuit, 2\spadesuit, ..., 10\spadesuit, J\spadesuit, Q\spadesuit, K\spadesuit, & A\clubsuit, 2\clubsuit, ..., 10\clubsuit, J\clubsuit, Q\clubsuit, K\clubsuit \end{array} \right\}$, then $p(A) = \frac{1}{2}$.

Outline

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Priority Queue

Wikipedia

- In computer science, a priority queue is an abstract data type which is like a regular queue or stack data structure, but where additionally each element has a "priority" associated with it. In a priority queue, an element with high priority is served before an element with low priority.
- While priority queues are often implemented with heaps, they are conceptually distinct from heaps. A priority queue is an abstract concept like "a list" or "a map";

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C++ STL Priority Queue

std::priority_queue

template <class T, class Container = vector<T>,
class Compare = less<typename Container::value_type>> class
priority_queue;

Priority queue

Priority queues are a type of container adaptors, specifically designed such that its first element is always the greatest of the elements it contains.

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The container shall be accessible through random access iterators and support the following operations:

- empty
- size
- front
- push_back
- pop_front

The standard container classes vector and deque fulfill these requirements. By default, if no container class is specified for a particular priority_queue class instantiation, the standard container vector is used.

Tries

- Let a **word** be a single string and let **dictionary** be a large set of words.
- The **set<string>** and the **hash tables** can only find in a dictionary words that match exactly with the single word that we are finding.
- **Trie** is a tree type data structure that allows to represent a dictionary.
  - We can insert and find strings in $\mathcal{O}(\mathrm{L})$.
  - We can perform incremental search.

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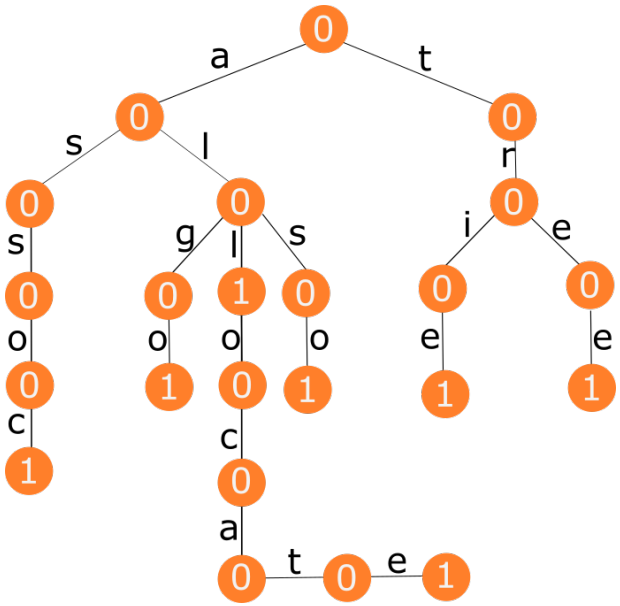
Tries

- The word **trie** is an infix of the word "re**trie**val" because the trie can find a single word in a dictionary with only a prefix of the word.
- The trie is a tree where each vertex represents a single word or a prefix.
  - The root represents an empty string ε.
  - A vertex that are k edges of distance of the root have an associated prefix of length k.
  - Let v and w be two vertexes of the trie, and assume that v is a direct father of w, then v must have an associated prefix of w.
  - Deterministic acyclic finite state automaton.

Tries: Example

- The following trie stores the words: “algo”, “assoc”, “all”, ”allocate”, “also”, “tree” and “trie”.



- Note that every vertex of the tree does not store entire prefixes or entire words.

How to represent tries?

- The most simple way to represent a trie is with an struct like following:

```
struct trie <typename Type = int> begin
    Type data;
    struct trie *edge[ALPHABET_SIZE];
end
```

- For the english alphabet, we can store the $'a'$-edge in $trie::edge[0]$, $'b'$-edge in $trie::edge[1]$, $'c'$-edge in $trie::edge[2]$ and so on until $'z'$-edge in $trie::edge[25]$.

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How to add a word to dictionary?

- We can add a word w as following:

function `add-word(`**struct** `trie` $*t$, **char** $*w$`)`**begin**
    if `is-empty(`w`)` **then:**
        $t->data \longleftarrow t->data+1;$
    else:
        if `is-null(`$t->edge[*w]$`)` **then:**
            $t->edge[*w] \longleftarrow$**new struct** `trie`;
        end
        `add-word(`$t->edge[*w], w+1$`);`
    end
end

How to find a word in dictionary?

- To find a word w, we can perform following algorithm:

function `find-word(`**struct** `trie` $*t$, **char** $*w$`)`**begin**
    if `is-null(t)` **then: return** 0;
    if `is-empty(`w`)` **then: return** $t->data$;
    return `find-word(`$t->edge[*w], w+1$`);`
end

Outline

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Huffman Encoding

- The idea is... blah blah

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Statistical

- Statistical Pattern Recognition
  - Principal Component Analysis
- Digital Signal Processing
  - Filtering
- Image compression
  - Grayscale images
  - Color images

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References I

- Wikipedia