#### Basics

The robo

Software

Inter-thread communication Application logi Robot controlle

Experimen

### LMHanoi - Tower of Hanoi with Lego Mindstorms

Markus Flatz, Peter Palfrader, Andreas Rottmann

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### Overview

Basics

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C - G

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- 1 Basics
- 2 The robot
- 3 Software

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### The puzzle

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Move a set of disks from one rod to another



### The puzzle

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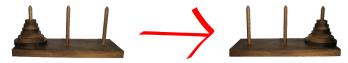
he robot

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Experimen

• Move a set of disks from one rod to another



• With moving only ever one disk

### The puzzle

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Experimen

• Move a set of disks from one rod to another



- With moving only ever one disk
- No larger disk may rest on a smaller one



## Lego Mindstorms

#### Basics

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- Extends Lego with new building blocks:
  - Sensors
  - Motors
  - Programmable computer
- NXT 2.0: 32-bit ARM7 microprocessor, 64 kB RAM and 256 kB Flash memory
- 4 input, 3 output ports
- Bluetooth, USB
- Sound

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# ABuNQEUC<sup>1</sup> NXC Not eXactly C

- Free compiler to build Lego Mindstorms executables from something similar to C
- Somewhat documented
- Several limitations, e.g., no recursion, no passing of mutexes as parameters
- Workarounds require abusing the preprocessor

#### The robot: Klaus

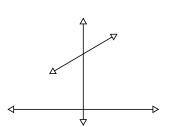
Rasics

#### The robot

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- Forklift
- Can move along three axes





- Movement limited by sensors for two of them
- Using touch and color sensors

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Rasics

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#### Software

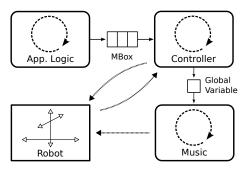
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#### Three threads

- Application logic (Tower of Hanoi algorithm)
- Robot controller
- Music playback

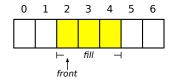
#### Inter-thread communication

Inter-thread communication

#### **NXC** Primitives

Mutex

#### Mailbox



- Circular buffer
- Mutex (protects fill count and front pointer)
- Two counting semaphores (full, empty)[1]

## Application logic

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• Determine movement sequence

### Recursive algorithm

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```
void hanoi(int n, rod source, rod help, rod dest) {
   if (n > 0) {
      hanoi(n - 1, source, dest, help);
      move_disk(source, dest);
      hanoi(n - 1, help, source, dest);
   }
}
```

### Recursive algorithm

#### Basics

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```
 \begin{array}{c} \textbf{void} \ \ \text{hanoi} (\textbf{int} \ n, \ \text{rod source} \ , \ \text{rod help} \ , \ \text{rod dest} \ ) \ \{ \\ \textbf{if} \ (n > 0) \ \{ \\ \text{hanoi} (n - 1, \ \text{source} \ , \ \text{dest} \ , \ \text{help} \ ); \\ \text{move\_disk} (\textbf{source} \ , \ \text{dest} \ ); \\ \text{hanoi} (n - 1, \ \text{help} \ , \ \text{source} \ , \ \text{dest} \ ); \\ \} \\ \} \end{array}
```

•  $2^n - 1$  moves

### Recursive algorithm

#### Basics

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```
void hanoi(int n, rod source, rod help, rod dest) {
   if (n > 0) {
      hanoi(n - 1, source, dest, help);
      move_disk(source, dest);
      hanoi(n - 1, help, source, dest);
   }
}
```

- $2^n 1$  moves
- Optimal movement sequence

## Iterative algorithm [2],[3]

#### **Basics**

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- Rods source, help and destination on a circle
- Even number of disks: ordered clockwise
- Odd number of disks: ordered counterclockwise

## Iterative algorithm [2],[3]

#### **Basics**

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- Rods source, help and destination on a circle
- Even number of disks: ordered clockwise
- Odd number of disks: ordered counterclockwise

```
while (not all disks on destination rod) {
   move the smallest disk one rod clockwise;
   if (a disk other than the smallest can be moved) {
      move this disk;
   }
}
```

## Iterative algorithm [2],[3]

#### **Basics**

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- Rods source, help and destination on a circle
- Even number of disks: ordered clockwise
- Odd number of disks: ordered counterclockwise

```
while (not all disks on destination rod) {
   move the smallest disk one rod clockwise;
   if (a disk other than the smallest can be moved) {
      move this disk;
   }
}
```

• Same movement sequence

## Implementation

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- No support for recursion
- Choose iterative algorithm

## Naïve implementation

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	help	dest.	source	 dest.
disk	1	2	3	 n

• Store the current location of each disk

## Naïve implementation

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Application logic

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	help	dest.	source	 dest.
disk	1	2	3	 n

- Store the current location of each disk
- Space complexity:  $\mathcal{O}(n)$

### Naïve implementation

**Basics** 

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	help	dest.	source		dest.
disk	1	2	3		n

- Store the current location of each disk
- Space complexity:  $\mathcal{O}(n)$
- Time complexity per move:  $\mathcal{O}(n)$

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source	3			
help	4	1		
destination	5	2		

height: 1 2 2 source help dest.

Store the disks on each rod

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source	3			
help	4	1		
destination	5	2		

height:	1	2	2
	source	help	dest.

- Store the disks on each rod
- Store the height of each rod's stack



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source	3			
help	4	1		
destination	5	2		

height:	1	2	2
	source	help	dest.

- Store the disks on each rod
- Store the height of each rod's stack
- Approximately three times as much memory



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source	3			
help	4	1		
destination	5	2		

height:	neight: 1		2	
	source	help	dest.	

- Store the disks on each rod
- Store the height of each rod's stack
- Approximately three times as much memory
- Space complexity:  $\mathcal{O}(n)$



Application logic

source	3			
help	4	1		
destination	5	2		

height:

1	2	2
source	help	dest.

- Store the disks on each rod
- Store the height of each rod's stack
- Approximately three times as much memory
- Space complexity:  $\mathcal{O}(n)$
- Time complexity per move:  $\mathcal{O}(1)$

## Robot controller (1)

**Basics** 

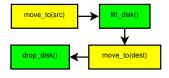
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#### General structure



- Get movements from mailbox and execute them
- Maintains current position
- Wagon position stops on color sensor readings
- Fork vertical movement stops on touch sensor
- Fork moves horizontally by fixed amount

## Robot controller (2)

Basics

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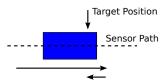
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### **Specialties**

Overshoot



## Robot controller (2)

Basics

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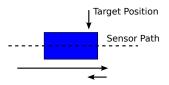
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#### **Specialties**

Overshoot



• Use raw mode of color sensor to detect blue

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Additional concurrency

### Music

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#### Music

- Additional concurrency
- Situational

$$duration(n) = (2^n - 1) \cdot d + c$$

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## Experiment

$$duration(n) = (2^n - 1) \cdot d + c$$

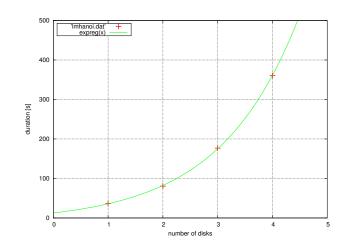


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Music Experiment



### Experiment

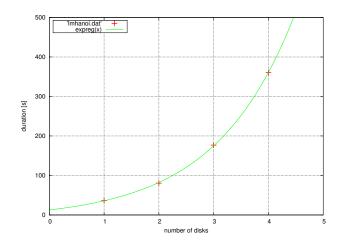
$$duration(n) = (2^n - 1) \cdot d + c$$



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$$expreg(x) = (e^{0.693 \cdot x} - 1) \cdot 23.2 + 12.7$$



#### References

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https:

//secure.wikimedia.org/wikipedia/de/w/index.
php?title=T%C3%BCrme\_von\_Hanoi&oldid=83701385.

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Thank you for your attention.