



Technische
Universität
Braunschweig



Algorithmen und Datenstrukturen

Detour: Tilt Probleme

Arne Schmidt

12.01.2023

Murmelspiel

Murmelspiel



- Bewege Murmel vom Start ins Ziel.
- Murmel darf nicht in ein Loch fallen.
- Murmal kann nur extern durch Schwerkraft kontrolliert werden.

Mehrere Murmeln bewegen sich alle in die gleiche Richtung!

Murmelspiel

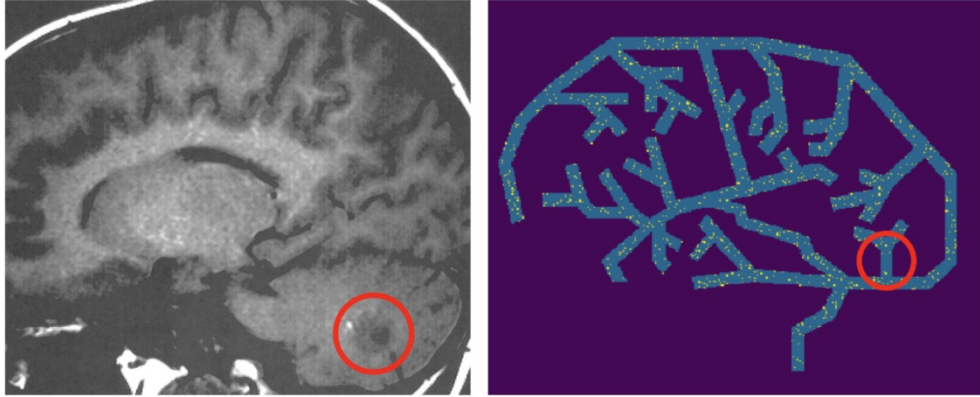


Fig. 1. (Left) An MRI image of a brain tumor (marked by the red circle), located in the cerebellum. (Right) How can the swarm of particles (indicated by yellow dots) be delivered to the target region?

- Bewege Murmel vom Start ins Ziel.
- ~~Murmel darf nicht in ein Loch fallen.~~
- Murmal kann nur extern durch Schwerkraft kontrolliert werden.

Mehrere Murmeln bewegen sich alle in die gleiche Richtung!

Gathering

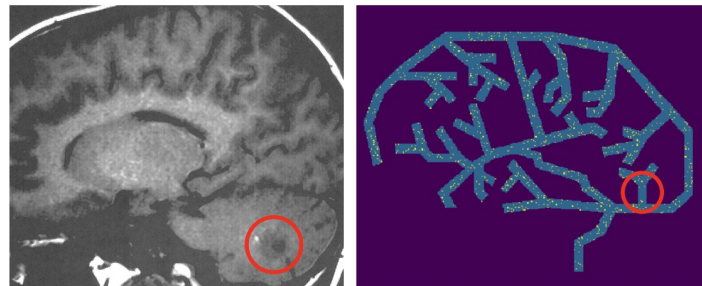
Gathering

2020 IEEE International Conference on Robotics and Automation (ICRA)
31 May - 31 August, 2020. Paris, France

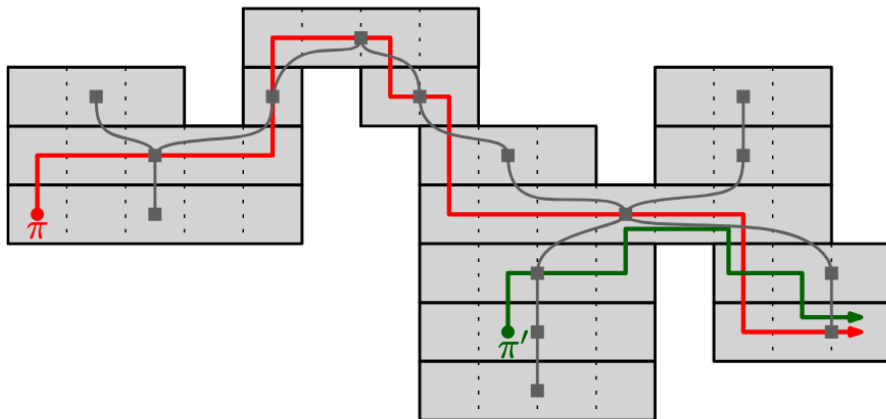
Targeted Drug Delivery: Algorithmic Methods for Collecting a Swarm of Particles with Uniform, External Forces

Aaron T. Becker^{*1}, Sándor P. Fekete^{*2}, Li Huang^{*1}, Phillip Keldenich^{*2},
Linda Kleist^{*2}, Dominik Krupke^{*2}, Christian Rieck^{*2}, Arne Schmidt^{*2}

Abstract— We investigate algorithmic approaches for targeted drug delivery in a complex, maze-like environment, such as a vascular system. The basic scenario is given by a large swarm of micro-scale particles (“agents”) and a particular target region (“tumor”) within a system of passageways. Agents are too small to contain on-board power or computation and are instead controlled by a global external force that acts uniformly on all particles, such as an applied fluidic flow or electromagnetic field. The challenge is to deliver all agents to the target region with a minimum number of actuation steps.



Gathering



Solang mind. zwei Partikel existieren:

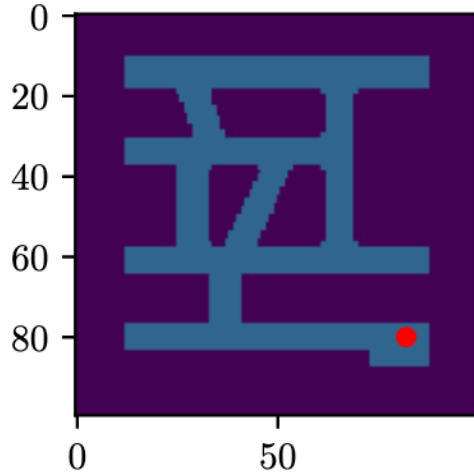
- Wähle zwei Partikel rot und grün.
- Betrachte kürzesten Pfad zwischen beiden.
- Bewege rot auf dem aktuell kürzesten Pfad, bis grün erreicht ist.

Breitensuche!

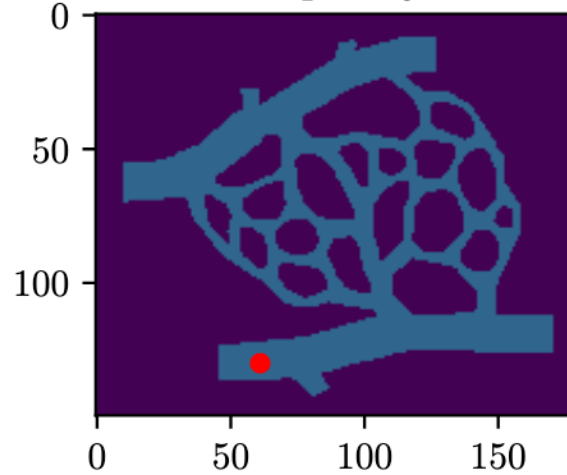
Gathering

Test Instanzen

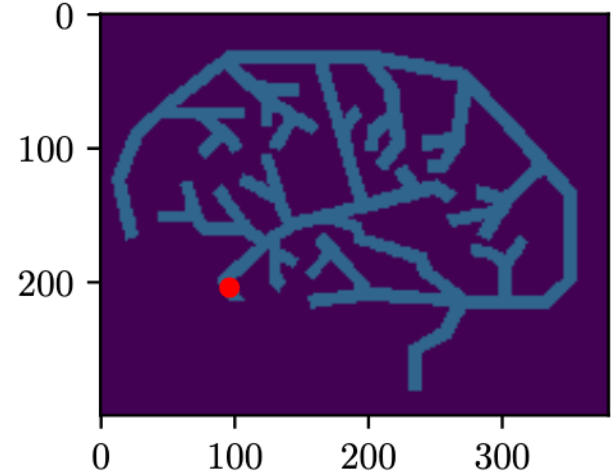
Corridor



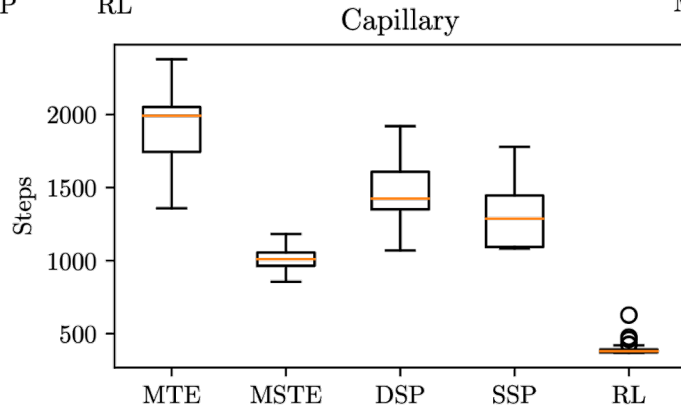
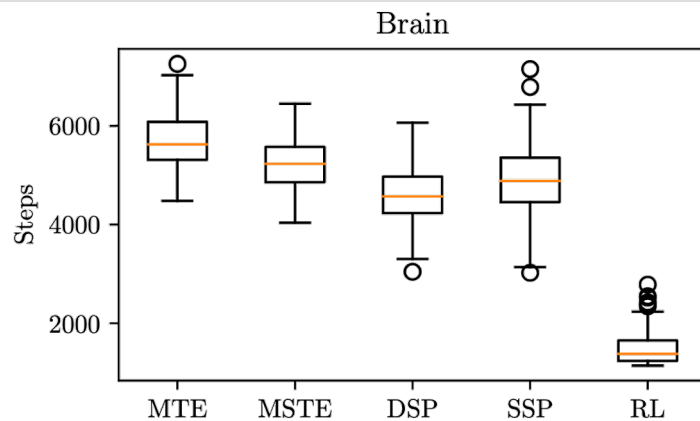
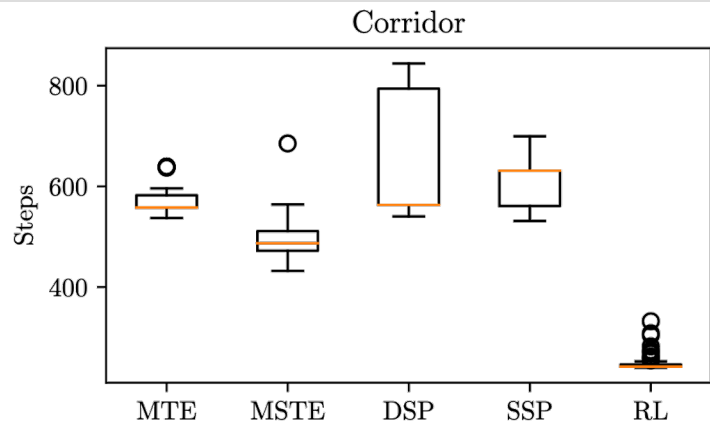
Capillary



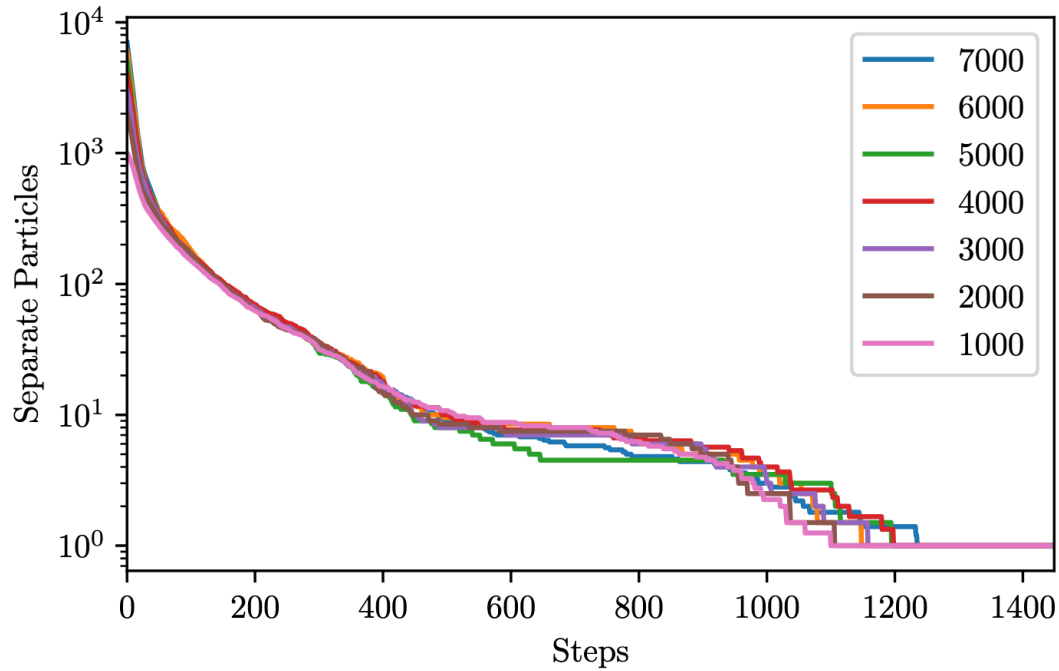
Brain



Gathering

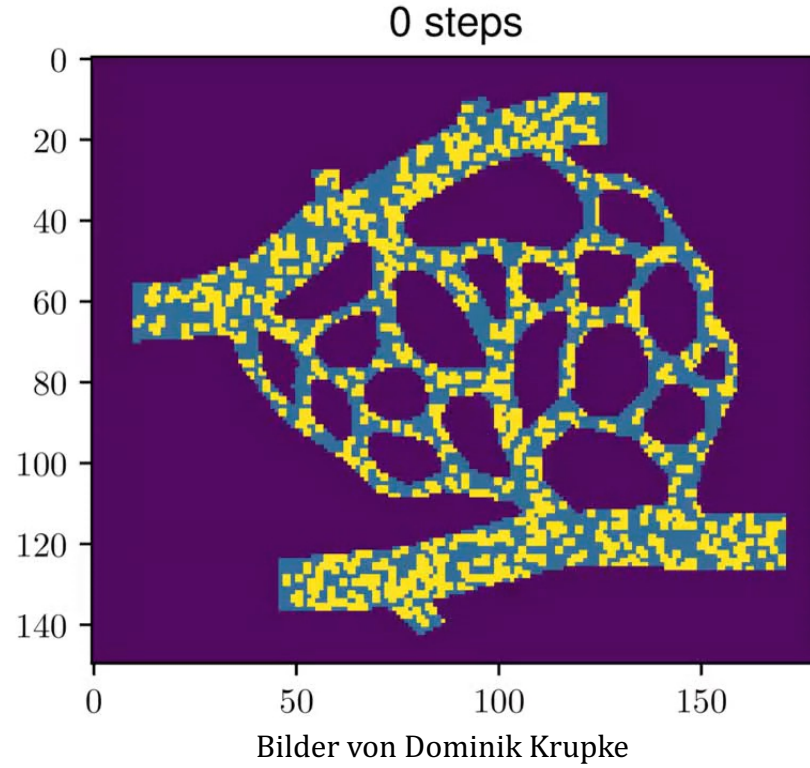


Gathering

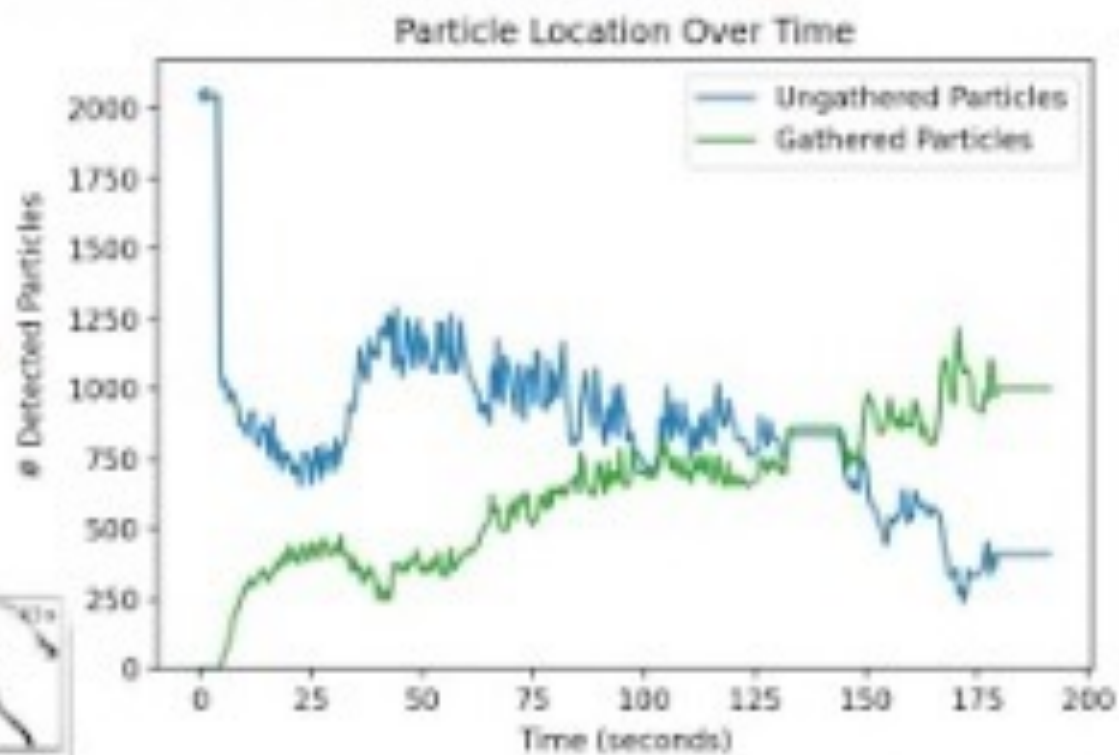
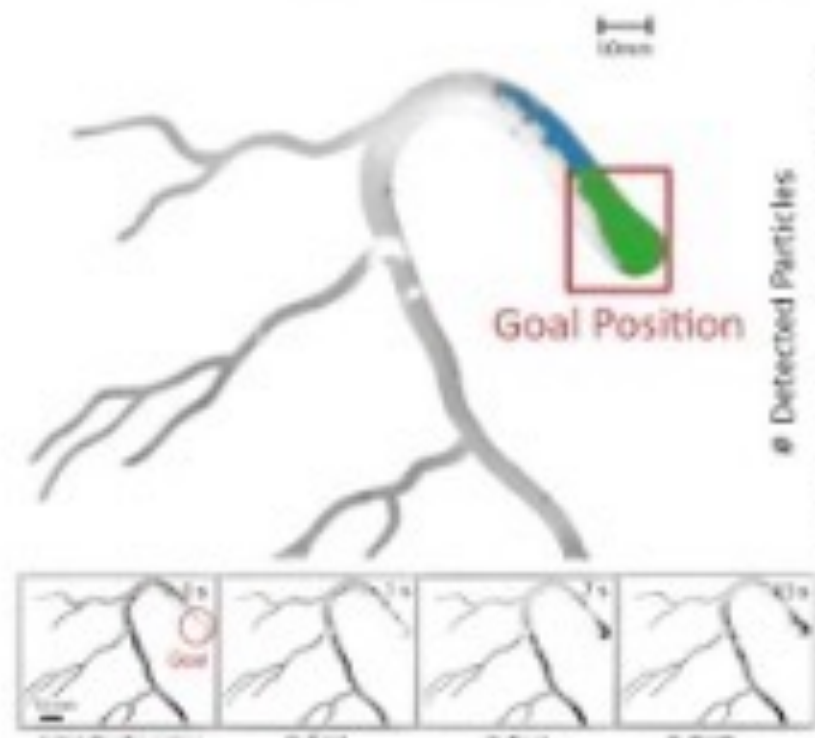


Zusammenbringen der letzten Partikel benötigt viel Zeit!

Gathering



Gathering Magnetic Particles with Reinforcement Learning





hardware
demonstration

2x video speed



*reenactment

Full Tilt Assembly

Bewegung, bis Hindernis oder
andere Partikel getroffen.

Assembly

Algorithmica (2020) 82:165–187
<https://doi.org/10.1007/s00453-018-0483-9>

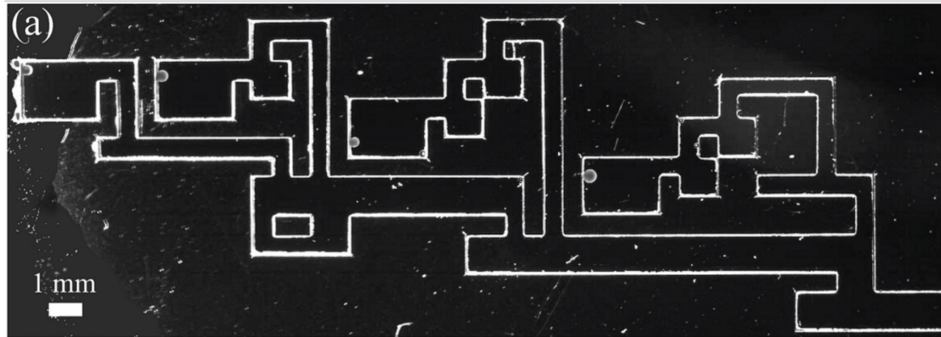


Tilt Assembly: Algorithms for Micro-factories That Build Objects with Uniform External Forces

Aaron T. Becker¹  · Sándor P. Fekete²  · Phillip Keldenich²  ·
Dominik Krupke²  · Christian Rieck²  · Christian Scheffer²  ·
Arne Schmidt² 

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Assembly



- Partikel kleben einander
- Bewegung bis ein Hinderniss getroffen wird

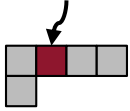
Aufgabe

Konstruiere eine bestimmte Form.



Drop Shapes

Fixiertes Seed-Partikel



Schieße Partikel aus den Richtungen
N, E, S, W

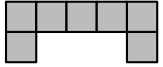
Drop Shapes



Schieße Partikel aus den Richtungen
N, E, S, W

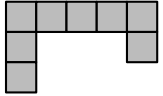


Drop Shapes



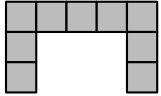
Schieße Partikel aus den Richtungen
N, E, S, W

Drop Shapes



Schieße Partikel aus den Richtungen
N, E, S, W

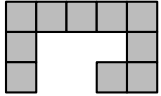
Drop Shapes



Schieße Partikel aus den Richtungen
N, E, S, W



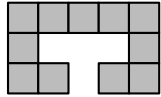
Drop Shapes



Schieße Partikel aus den Richtungen
N, E, S, W

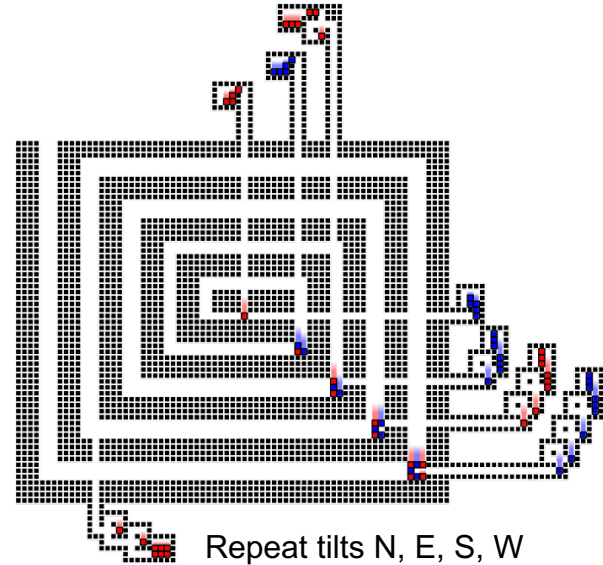
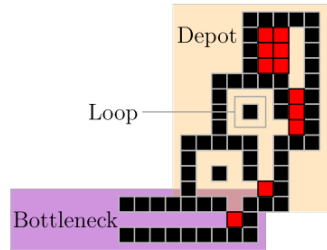
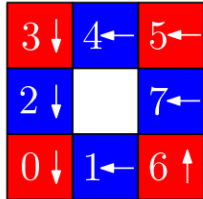


Drop Shapes



Schieße Partikel aus den Richtungen
N, E, S, W

Generierung eines Labyrinths:



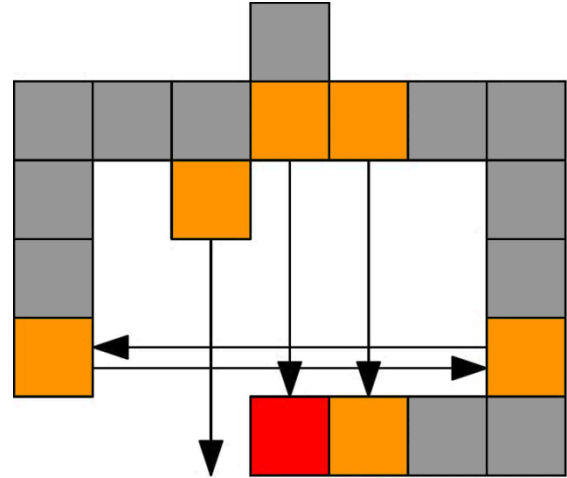
Entscheide (De-)Konstruierbarkeit

Einfache Polyominos

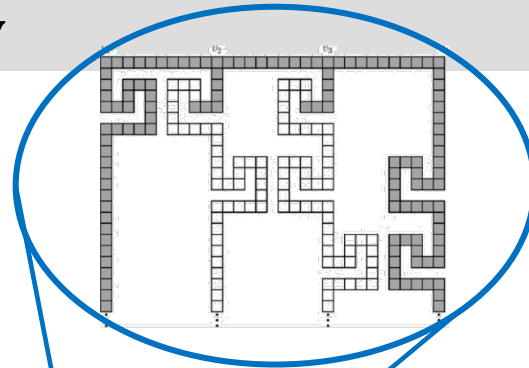
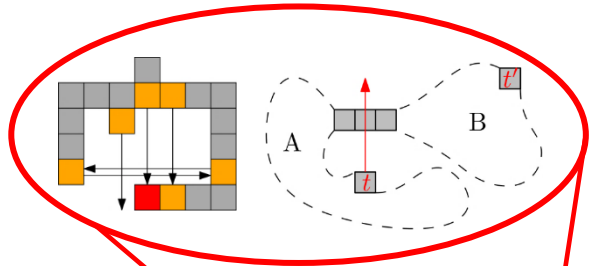
Repeat until candidates are empty:
 Entferne einen Kandidaten
 Aktualisiere Menge der Kandidaten
If (Partikel übrig) Then
 return **false**
Else
 return **true**

Laufzeit: $O(N \log N)$

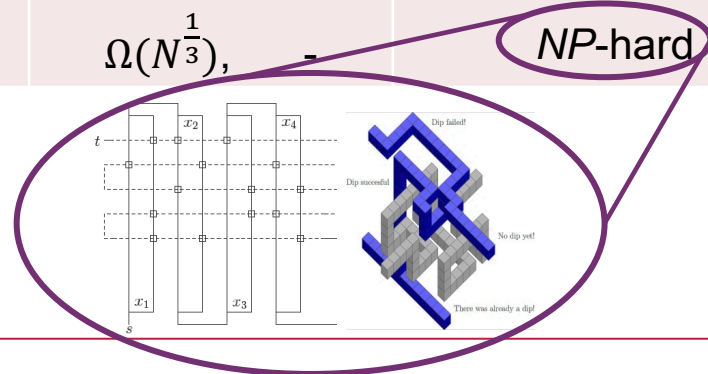
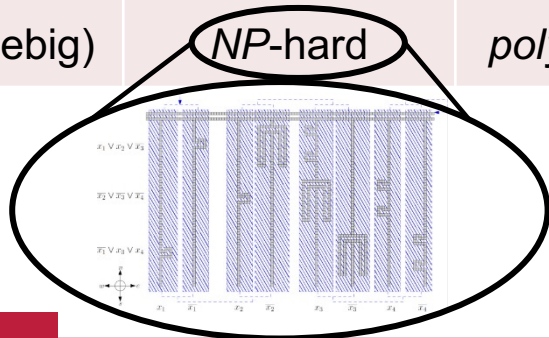
Dafür: Ein AVL-Baum
pro x und y Koordinate!



Ergebnisse Seeded Tilt Assembly

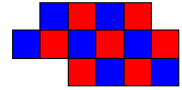


Dimension	Entscheidung	Optimierung	Approximation	Pfadkonstruktion
2D (einfach)	$O(N \log N)$	<i>polyAPX-hard</i>	$\Omega(N^{\frac{1}{3}}), O(N^{\frac{1}{2}})$	$O(N \log N)$
3D (beliebig)	<i>NP-hard</i>	<i>polyAPX-hard</i>	$\Omega(N^{\frac{1}{3}}), -$	<i>NP-hard</i>

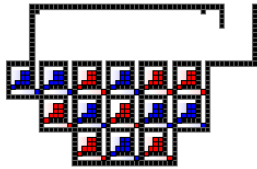


Parallel Assembly

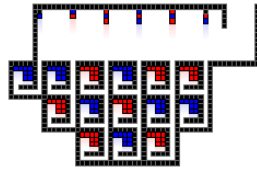
Parallel Tilt Assembly



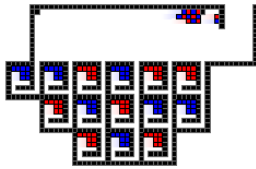
Polyomino P



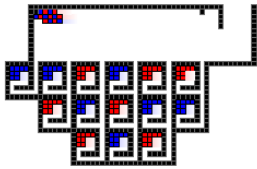
1. Right



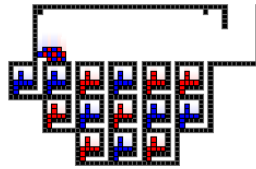
2. Up



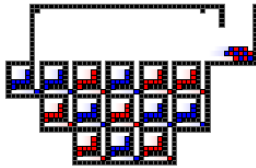
3. Right



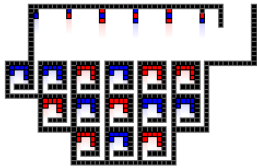
4. Left



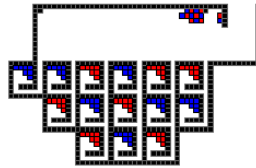
5. Down



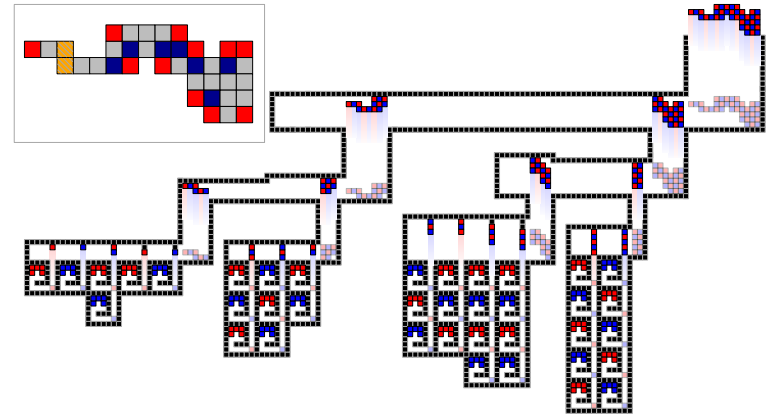
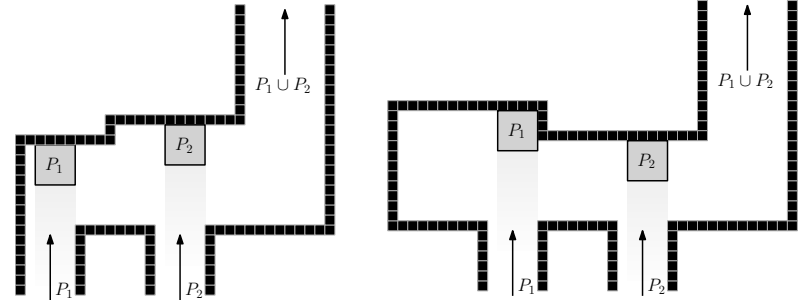
6. Right



7. Up

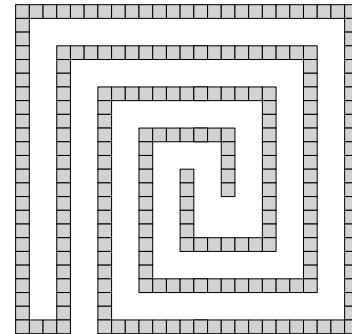
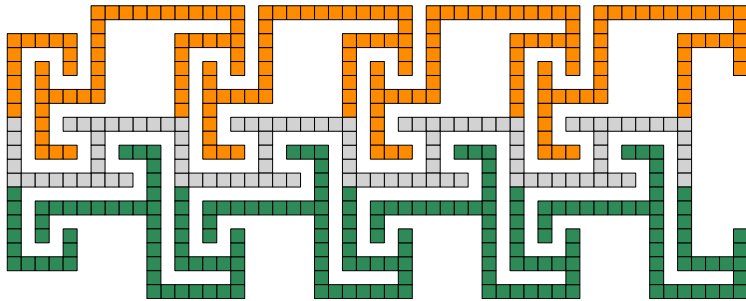


8. Right



Ergebnisse Parallel Tilt Assembly

Shape	Convex	Monotone	Simple	Convex holes
#Tilts	$O(1)$	$O(\log r)$	$O(r)$	$O(r)$
Time Finding Straight 2-Cuts	-	$O(N)$	$O(N + r^2 \log r)$	$O(N + r^3 \log N)$
Time Finding Arbitrary 2-Cuts	-	-	$O(r^3 N \log N)$	$O(r^4 N \log N)$



Single Step Assembly

Bewegung, wenn möglich, in die
gegebene Nachbarzelle.

Assembly

Particle-Based Assembly Using Precise Global Control

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Department of Computer Science, TU Braunschweig, Braunschweig, Germany

Christian Scheffer  

Faculty of Electrical Engineering and Computer Science, Bochum University of Applied Sciences, Bochum, Germany

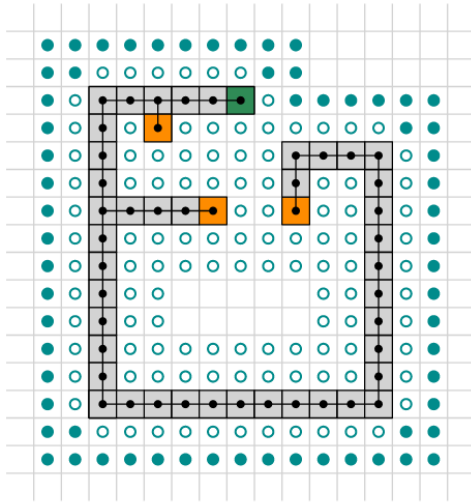
Arne Schmidt  

Department of Computer Science, TU Braunschweig, Braunschweig, Germany

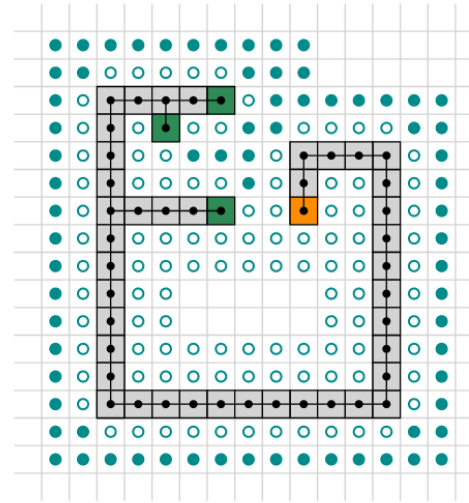
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Assembly

Bäume



(a)

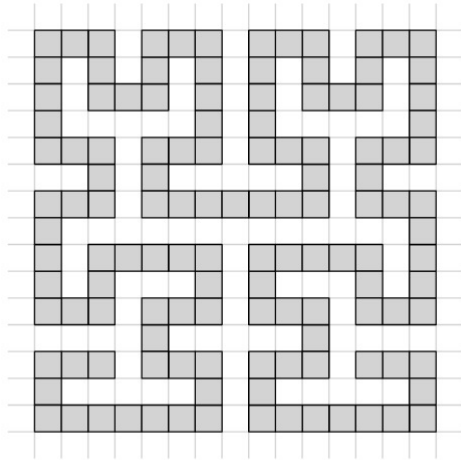


(b)

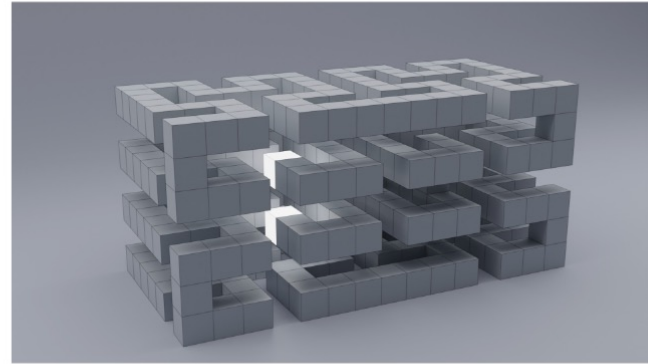
Baumstrukturen

Dank BFS/DFS in $O(N)$ Zeit entscheidbar, ob Form konstruierbar ist.

Assembly



(a)

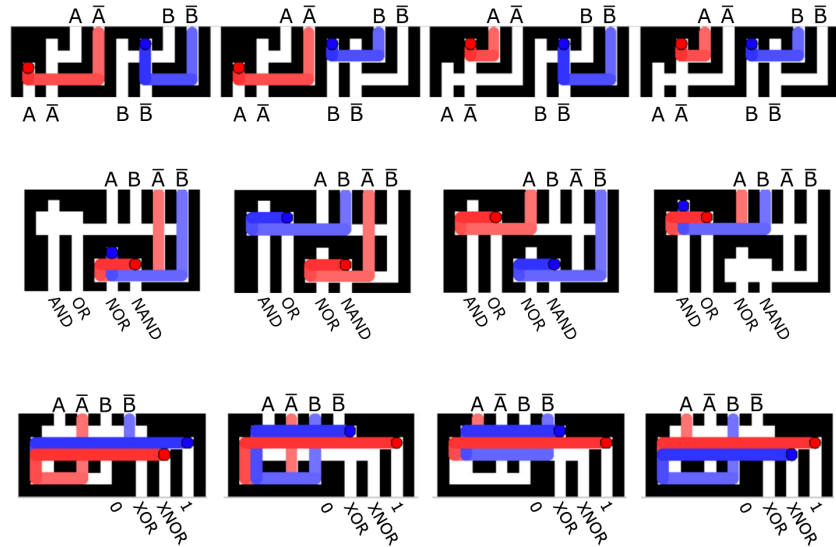
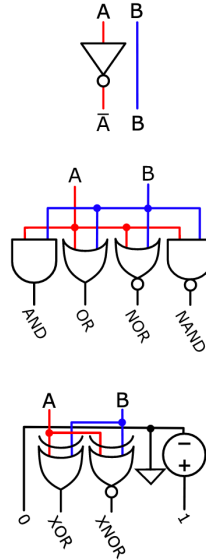
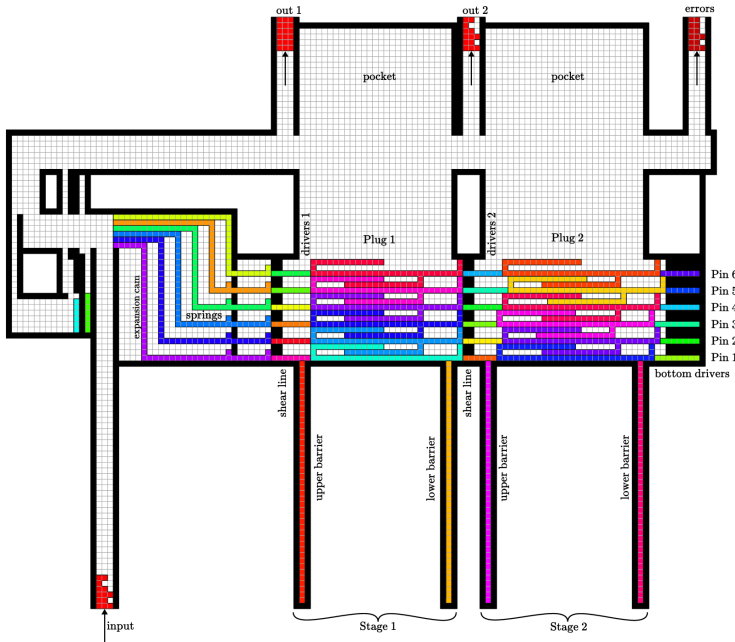


(b)

Nicht alles lässt sich konstruieren.

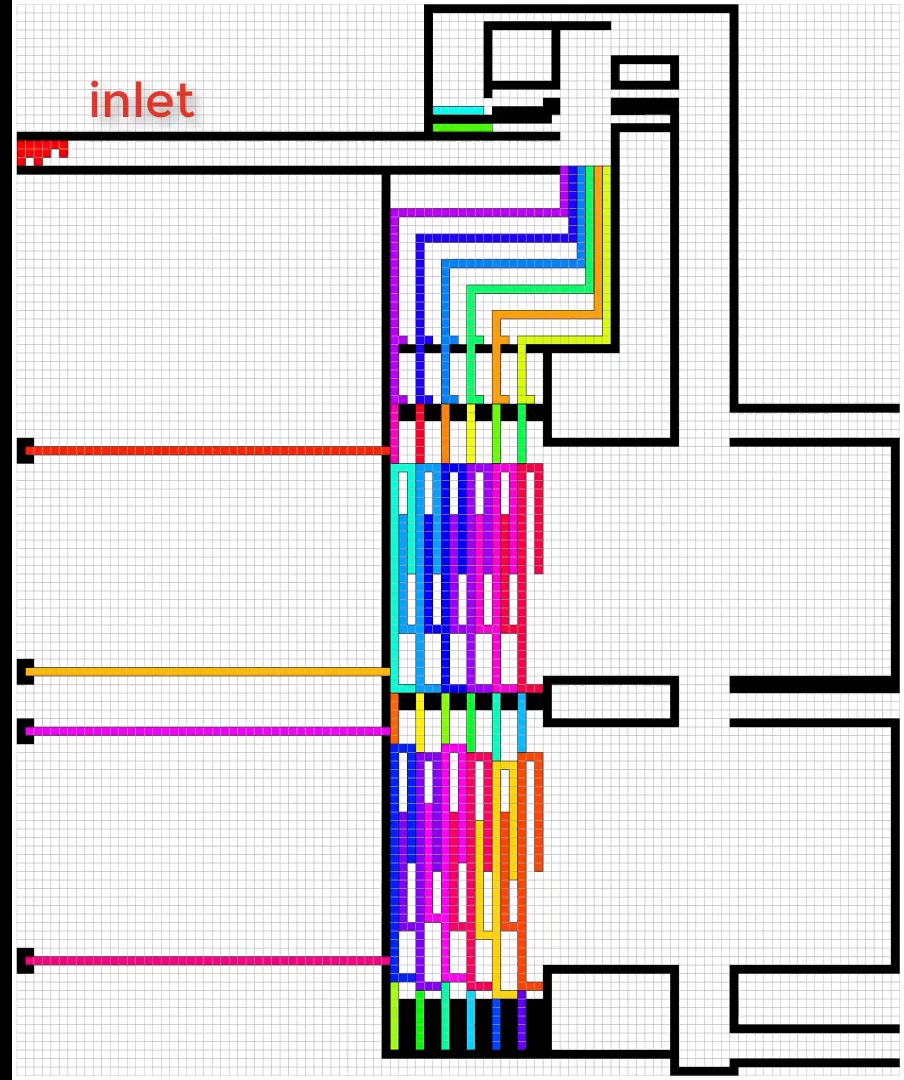
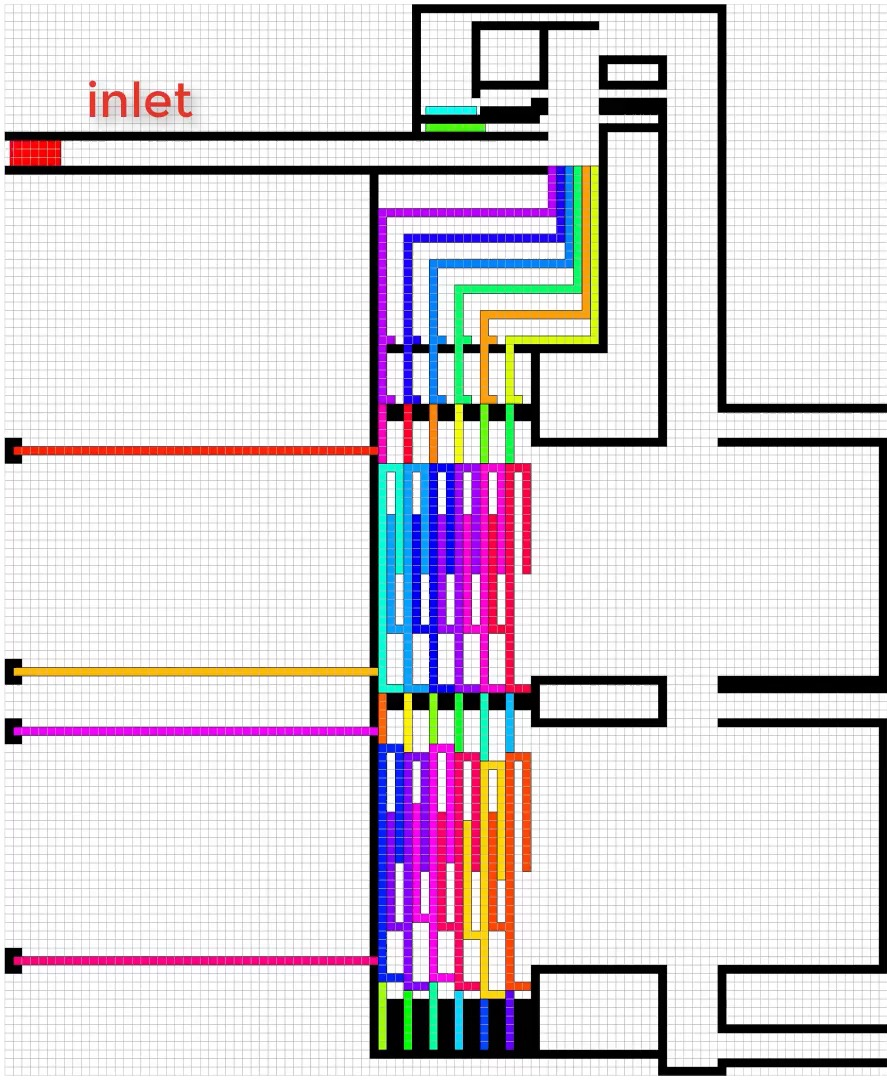
Weitere Probleme

Tilt Probleme

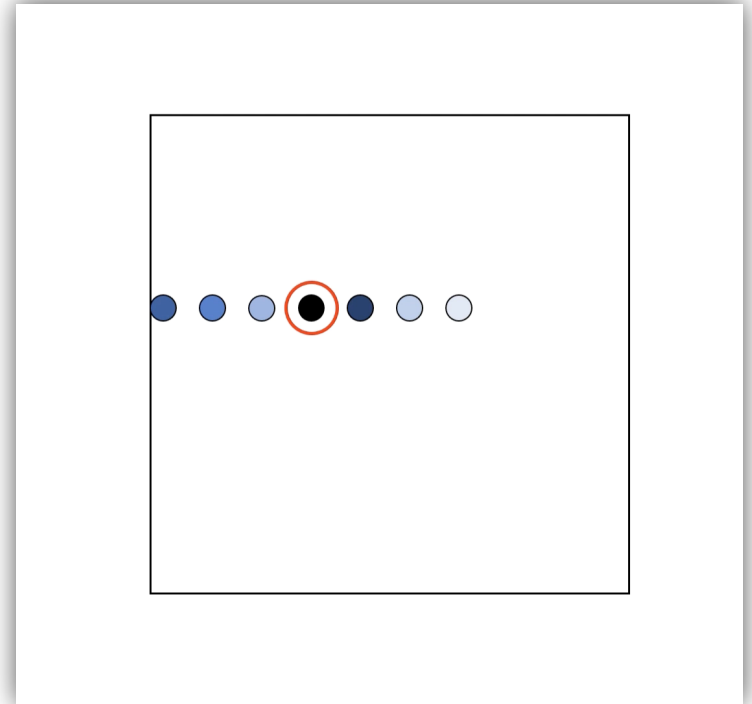
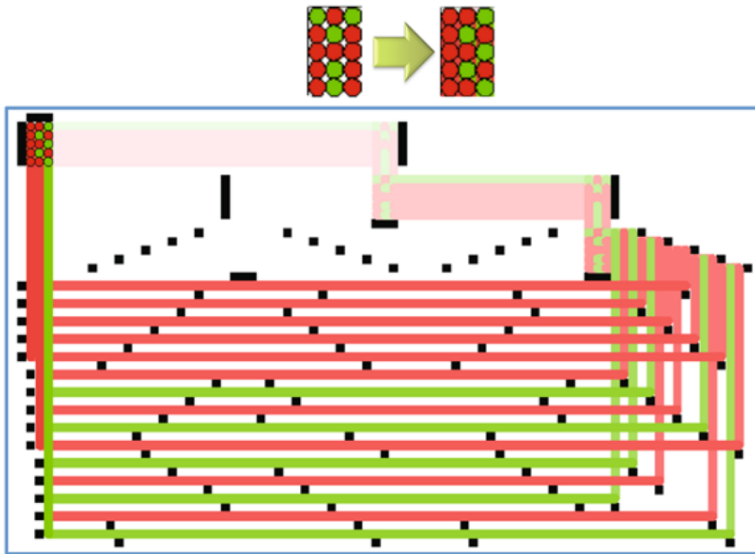


Klassifizierung von Formen

Realisieren von logischen Gattern

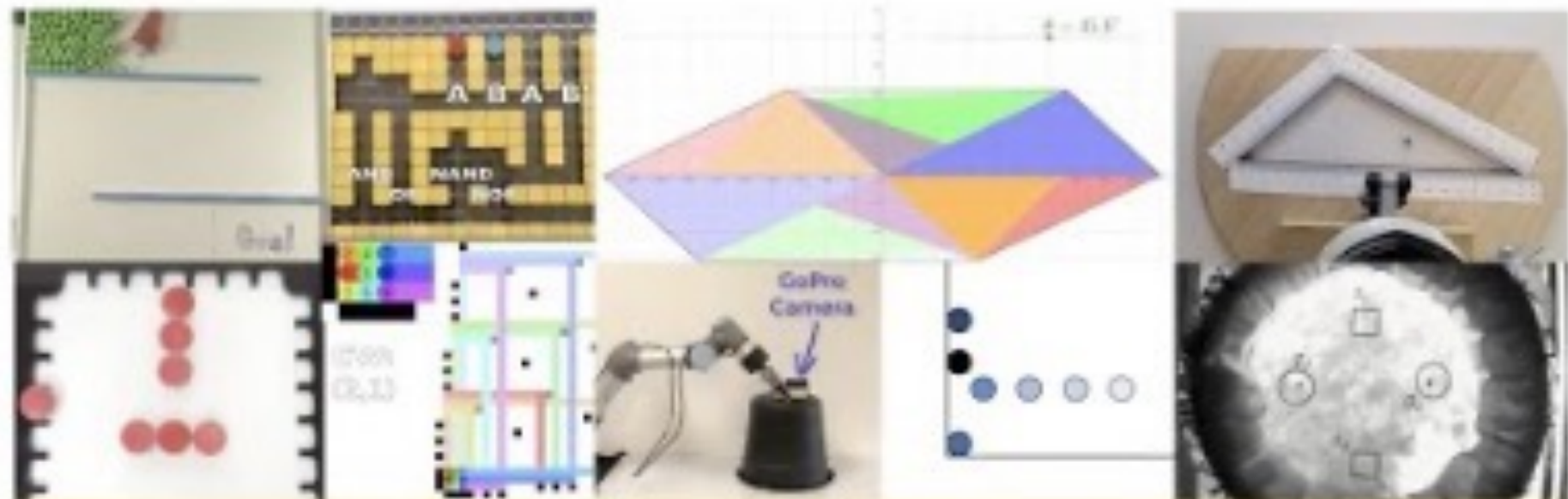


Tilt Probleme



Rekonfigurieren mit Hilfe von Hindernissen

Rekonfigurieren mit Hilfe von Reibungskräften



Coordinating Particle Relocation with Global Control and Local Friction

Victor M. Baez, Aaron T. Becker, Sándor P. Fekete, Arne Schmidt