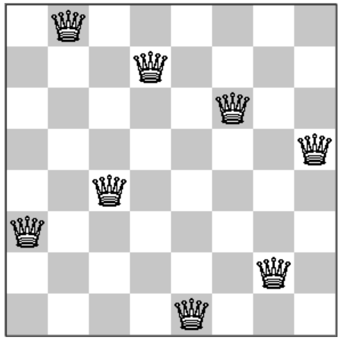
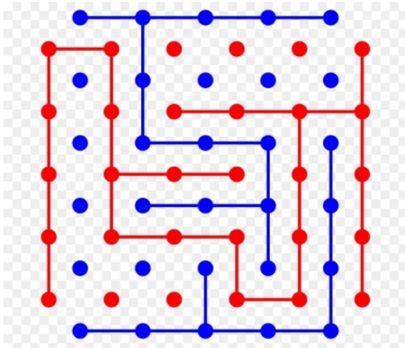
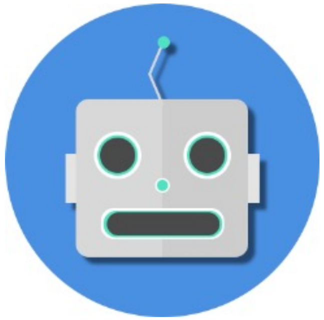
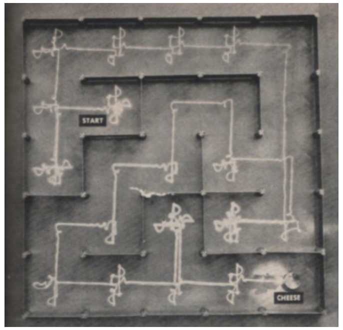
Artificial Intelligence:

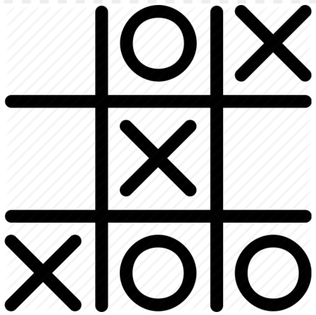
Past, Present and Future











TensorFlow

Chee Wei Tan

Some slides due to Matthew Wright and John Chase “How many ways are there to juggle” (2015)

Scientific Aspects of Juggling

Scientific Aspects of Juggling

Claude E. Shannon

> "Do you think juggling's a mere trick?" the little man asked, sounding wounded. "An amusement for the gapers? A means of picking up a crown or two at a provincial carnival? It is all those things, yes, but first it is a way of life, friend, a creed, a species of worship."
>
> "And a kind of poetry," said Carabella.
>
> Sleet nodded. "Yes, that too. And a mathematics. It teaches calmness, control, balance, a sense of the placement of things and the underlying structure of motion. There is a silent music to it. Above all there is discipline. Do I sound pretentious?"
>
> Robert Silverberg, *Lord Valentine's Castle*.

The little man Sleet in Silverberg's fantasy who so eloquently describes the many faces of juggling is a member of a juggling troupe on a very distant planet, many centuries in the future. We shall discuss some of the many dimensions of juggling on our tiny planet Earth from the viewpoints of Darwin (What is the origin of the species *jongleur?),* Newton (What are the equations of motion?), Faraday (How can it be measured?) and Edison (Can American inventiveness make things easier?). But we shall try not to forget the poetry, the comedy and the music of juggling for the Carabellas and Margaritas future and present. Does this sound pretentious?

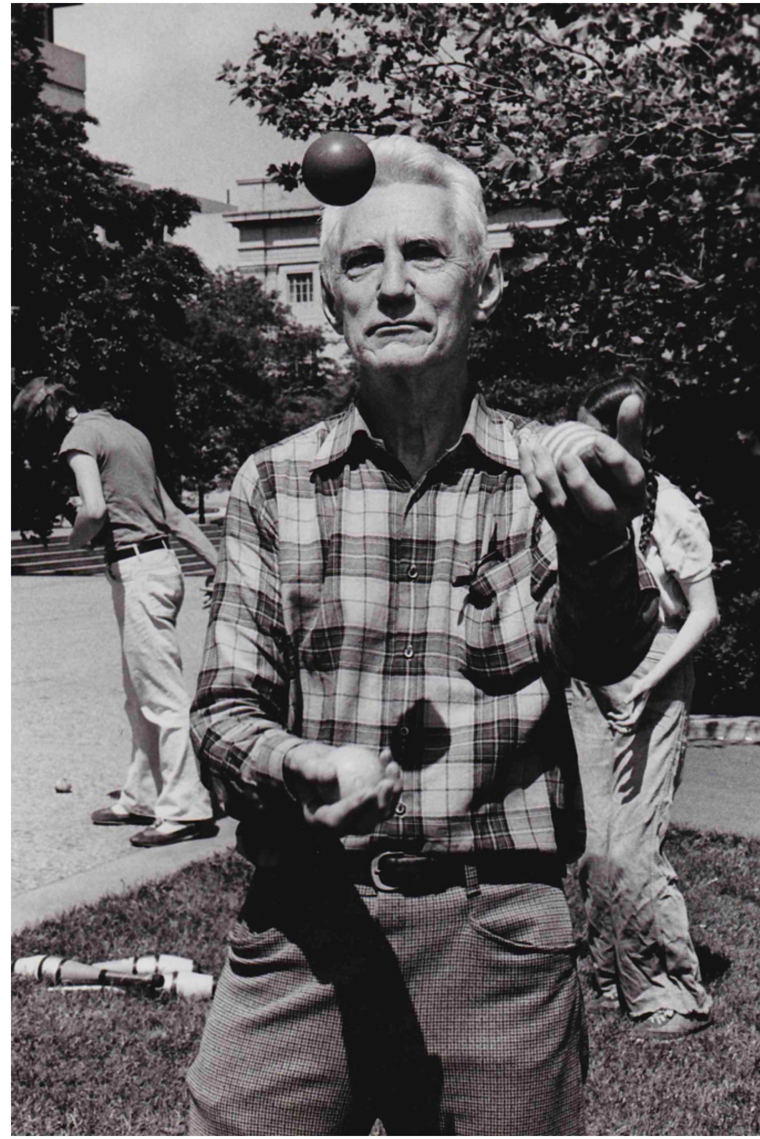
On planet Earth, juggling started many centuries ago and in many different and distant civilizations. A mural on the Egyptian tomb of Beni-Hassan dating back to 1900 B.C. shows four women each juggling three balls (Fig. 1). Juggling also developed independently at very early times in India, the Orient, and in the Americas among the Indians and Aztec cultures.

The South Sea island of Tonga has a long history of juggling. George Forster, a scientist on one of Captain Cook's voyages, wrote:

> "This girl, lively and easy in all her actions, played with five gourds, of the size of small apples, perfectly globular. She threw them up into the air one after another continually, and never failed to catch them all with great dexterity, at least for a quarter of an hour."

The early Greek historian Xenophon, about 400 B.C., describes in *The Banquet* the following incident.

> "At that, the other girl began to accompany the dancer on the flute, and a boy at her elbow handed her up the hoops until he had given her twelve. She took these and as she danced kept throwing them whirling into the air, observing the proper height to throw them so as to catch them in regular rhythm. As Socrates looked on he remarked: 'This girl's feat, gentlemen, is only one of many proofs that woman's nature is really not a whit inferior to man's, except in its lack of judgment and physical strength.' "

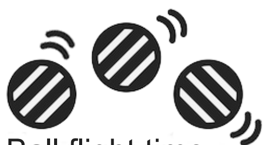


Claude E. Shannon: Collected Papers. Edited by N.J.A. Sloane and A. D. Wyner. IEEE Press, 1993.

Scientific Aspects of Juggling

All dwell times(D), flight times(F) and vacant times (V) are the same for all the hands.

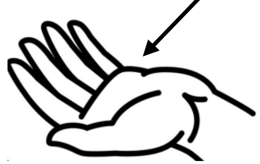
Shannon's Juggling Theorem : The proportionality between the number of balls(B) and hands(H) is given as



Ball flight time

$$\frac{B}{H} = \frac{F + D}{V + D}$$

Time a ball spends in a hand/
Time a hand is full



Time hand is vacant

Time a ball spends in a hand/
Time a hand is full

The Physics of Juggling

By Bengt Magnusson and Bruce Tiemann

Juggling, the art of controlling more objects up in the air than you have hands, has amazed and entertained people for thousands of years. From ancient Egyptian hieroglyphics through old Japanese woodcuts to present day photographs, we have images and stories of people manipulating stunning numbers of objects. A nameless Egyptian 4000 years ago was said to be able to juggle nine balls. Two Japanese jugglers, both living many hundred years ago, have also left their marks in the history of juggling. One was said to have stopped a war with his nine-ball juggling. His enemies fled in panic before his supposed magic since nobody but a powerful sorcerer could possibly perform such a feat. The other could juggle seven swords. Early in our own century, Jenny Yaeger and Enrico Rastelli set records by becoming the only people ever to verifiably juggle ten balls each. That number was surpassed recently, but with an easier juggling prop, when Sergei Ignatov and Albert Petrovsky successfully juggled eleven rings each. Yet a juggler does not need large numbers of objects to spellbind an audience, as shown by present-day performers such as Michael Moshen and the Airjazz trio. Three-ball juggling has enough potential to keep a creative juggler busy for a lifetime.

Many people have asked themselves how jugglers can perform the tricks they do. How is it possible to control all the objects in the air? A first step towards an answer to this question would be to explore the basic physical laws that govern the activity. Being both physicists and active jugglers, we set out to discover some of these laws almost three years ago during our senior year at the California Institute of Technology. While the physics involved does not go beyond the level of a first-term freshman, this exercise of ours has been very entertaining and also an opportunity for "playing by the seashore."

The fundamental observation, familiar to any juggler, is that all basic juggling is performed in a very strong pattern, where each hand does exactly the same thing. The basic pattern, which is the same no matter what kind of objects are being juggled, comes in two versions, one used when an odd number of objects are juggled, and one used for an even number. For odd numbers, each hand throws the object in an arc across to the other hand, where it is caught and thrown back in a similar arc. The object is released close to the center of the pattern and is caught on the outside. The two arcs intersect in front of the juggler, and each object visits both hands. This pattern is called the *cascade* (Fig. 1). For even numbers, each hand throws the object from the inside, and the same hand catches it on the outside. The two arcs do not intersect, and the objects never switch hands. This pattern is called the *fountain* (Fig. 2). Most nonjugglers have the misconception that all juggling takes place in a "circular" pattern. This variation is called the *shower* (Fig. 3) and is considerably harder than the patterns described above. In a shower, there is only one arc instead of two, and as a result there is much less time for each throw or the need for a much higher arc, both of which make the juggling harder. A pattern intermediate between the cascade and the shower, called the half-shower, is also fairly common.

To derive the relationship between throw height and number of balls in the basic patterns, we need to introduce a few variables. Let the time between consecutive throws from one hand be τ. The object will always spend some time in the hand: it is caught, carried over to the throwing position, and released. Call this time $\theta\,\tau$. θ is then the fractional dwell time, and $0 < \theta < 1$. Let n be the number of objects juggled, and h be the height of each throw.

First assume n is even. Each hand then has $\frac{1}{2}n$ objects, and it would take $\frac{1}{2}n\tau$ seconds for a hand to go through a full cycle. However, because of the dwell time, the first object must land a time $\theta\tau$ earlier, and the time t each object spends up in the air is $t = \frac{1}{2}n\tau - \theta\tau = \frac{1}{2}\tau(n - 2\theta)$. This formula holds true for odd n as well, although the derivation is somewhat different. Since $h = \frac{1}{8}gt^2$ we have, with $t = \frac{1}{2}\tau(n - 2\theta)$, that

$$h = \frac{1}{32}g(n - 2\theta)^2\tau^2 \qquad (1)$$

Bengt Magnusson *received his B.S. in physics from the California Institute of Technology in 1987 and is currently a third-year graduate student at the University of California at Santa Barbara. His field of research is experimental particle astrophysics. He has been juggling a little over three years and has reached the nine-ball/five-club level.*

Bruce Tiemann *received his B.S. in chemistry from the California Institute of Technology in 1987 and is currently working with nonlinear optical compounds at the Jet Propulsion Laboratory in Pasadena. He has been juggling for about ten years and performs "reasonably well" with seven clubs and eight balls. Other hobbies include building lasers and amateur radio.*

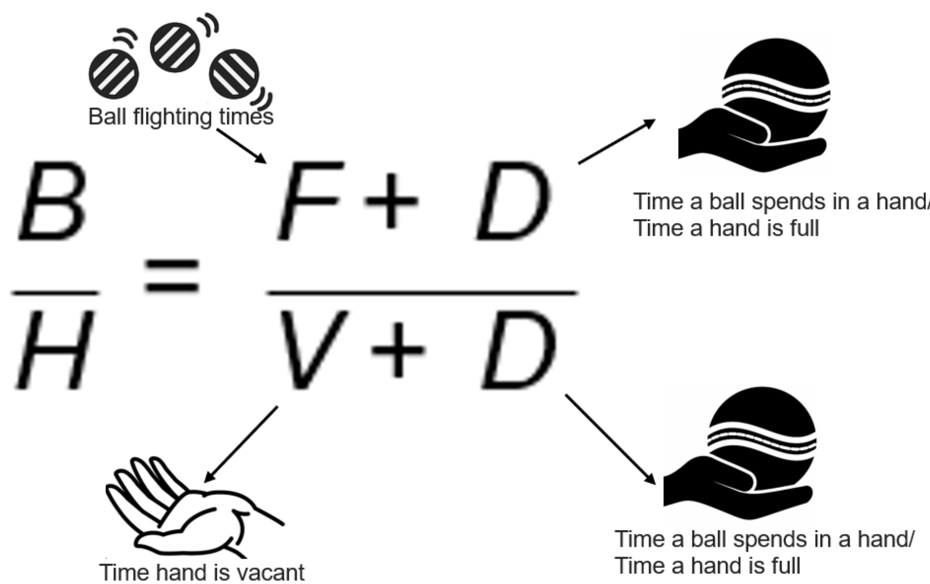
How Many Objects Can Human Juggle?

- Few people can juggle eleven or twelve objects and almost none so far for more than fifteen. Is this the human limit?
- Hand speed-eye coordination is crucial for feedback control to correct errors in throws.
- Other factors limiting the number of objects juggled are accuracy of throws, arm length and air space.

The Physics of Juggling

The number of hands and the timing of throws are abstracted away in Shannon's Juggling Theorem.

The physics of juggling starts with verifying the Shannon's Juggling Theorem to explore how fast or slow a person juggles.



https://www.seehuhn.de/pages/physics.html

An Example Illustrating The Timing of Throws

- The basis of our analysis is a sequence of pictures showing the sites-wap 4444535344 with a time resolution of 1/30 second. This table gives a time-line of events in the juggling sequence.

time	hand	ball	beat	event
0.100	R	green	1	throw 4
0.267	L	yellow	2	throw 4
0.433	L	red		catch
0.467	R	blue	3	throw 4
0.633	R	green		catch
0.700	L	red	4	throw 4
0.867	L	yellow		catch
0.933	R	green	5	throw 5
1.100	R	blue		catch
1.167	L	yellow	6	throw 3
1.367	L	red		catch
1.467	R	blue	7	throw 5
1.600	L	red	8	throw 3
1.633	R	yellow		catch
1.800	L	green		catch
1.967	R	yellow	9	throw 4
2.067	L	green	10	throw 4
2.100	L	red		catch

https://www.seehuhn.de/pages/physics.html

The Physics of Juggling

Verify that Shannon's Juggling Theorem holds for the sequence of throws

Left hand		Right hand	
holding	empty	holding	empty
1.234	0.766	1.368	0.632
0.100-0.267		0.100-0.467	
	0.267-0.433		0.467-0.633
0.433-0.700		0.633-0.933	
	0.700-0.867		0.933-1.100
0.867-1.167		1.100-1.467	
	1.167-1.367		1.467-1.633
1.367-1.600		1.633-1.967	
	1.600-1.800		1.967-2.100
1.800-2.067			
	2.067-2.100		
1.234	0.766	1.368	0.632

The Physics of Juggling

- *Measured holding and empty times for the hands in the interval from t=0.100 to t=2.100.*

green		yellow		blue		red	
air	hand	air	hand	air	hand	air	hand
1.433	0.567	1.199	0.801	1.266	0.734	1.500	0.500
0.100-0.633			0.100-0.267		0.100-0.467	0.100-0.433	
	0.633-0.933	0.267-0.867		0.467-1.100			0.433-0.700
0.933-1.800			0.867-1.167		1.100-1.467	0.700-1.367	
	1.800-2.067	1.167-1.633		1.467-2.100			1.367-1.600
2.067-2.100			1.633-1.967			1.600-2.100	
		1.967-2.100					
1.433	0.567	1.199	0.801	1.266	0.734	1.500	0.500

The Physics of Juggling

The quantities from Shannon's Juggling Theorem are

sum of holding times

= 1.234 + 1.368

= 0.567 + 0.801 + 0.734 + 0.500 = 2.602

sum of empty times

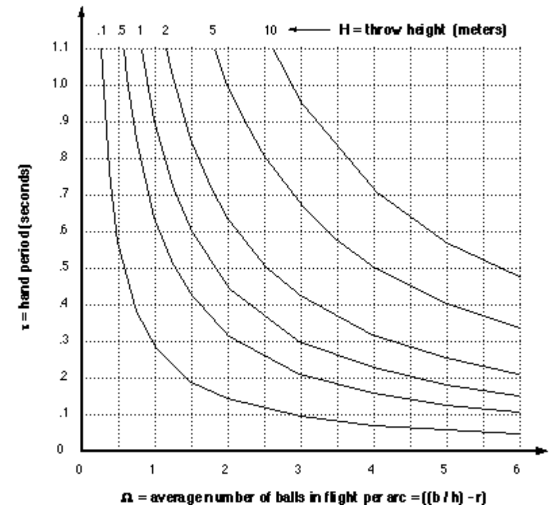
= 0.766 + 0.632

= 1.398

sum of flight times

= 1.433 + 1.199 + 1.266 + 1.500

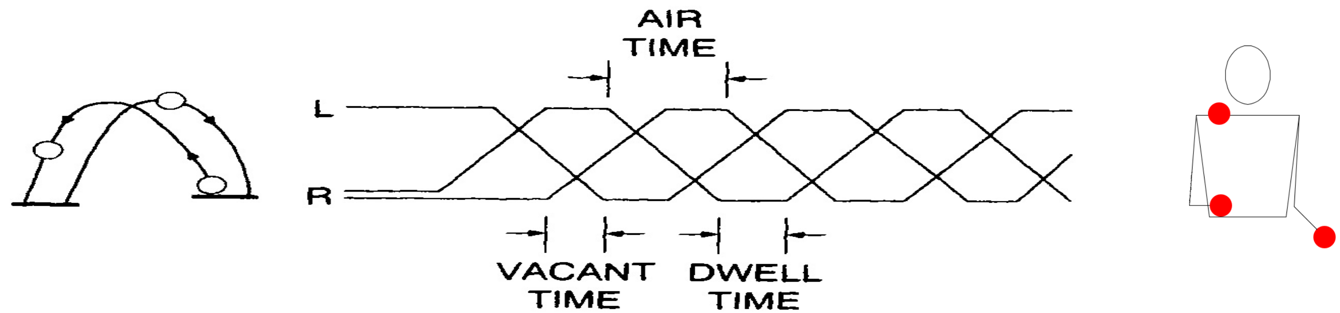
= 5.398



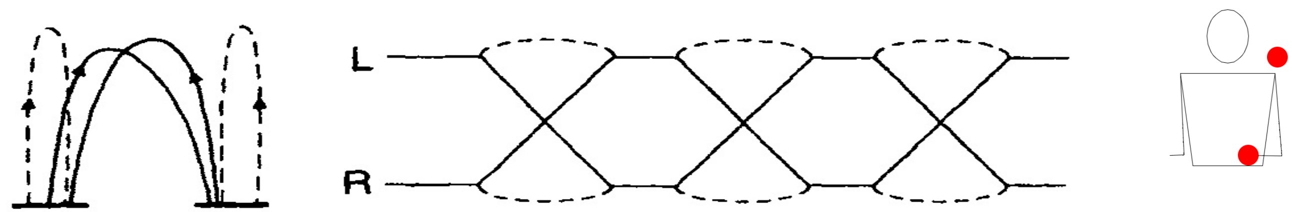
Thus the left-hand side of the equation in Shannon's Juggling Theorem becomes (2.602+5.398)/(2.602+1.398) = 8 / 4 = 2 as expected.

Patterns of Juggling

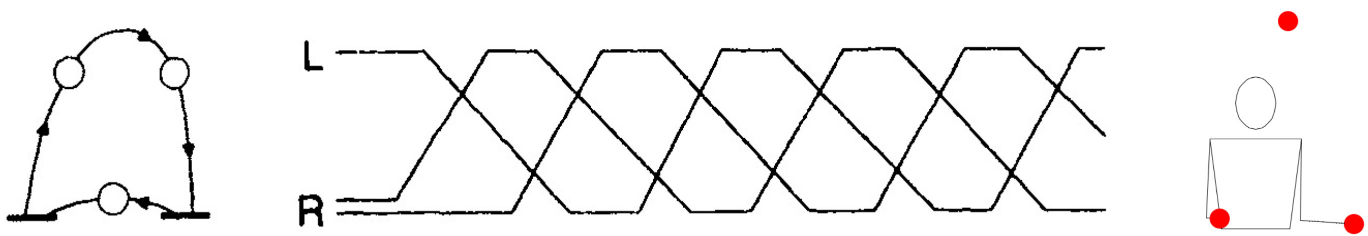
Three-ball cascade



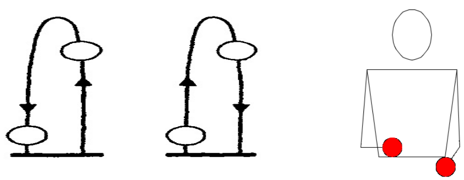
Two-ball cascade



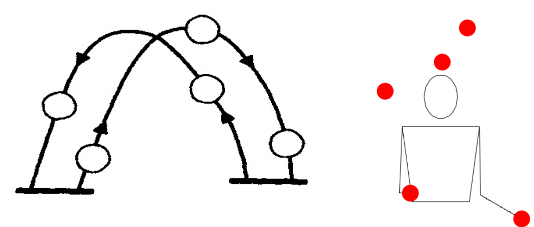
Three-ball shower



Three-ball fountain



Five-ball cascade



Patterns of Juggling

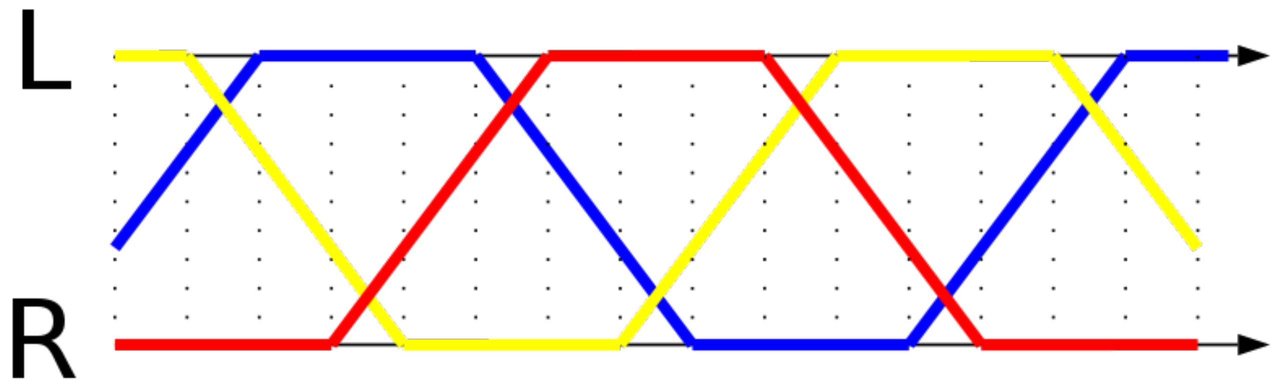
1. Two-ball cascade is the simplest case (i.e. two balls and two hands) where a choice can be made at each toss whether to interchange the balls or keep them in the same hands.

2. Three-ball cascade is the simplest pattern with three balls where jugglers can vary the height of the throw, the width of the hands and even reverse the direction of motion.

3. Three-ball shower is similar to the three-ball cascade but with different timing so that the whole pattern looks as if balls rotate in circles.

Let’s learn some simple two-ball and three-ball patterns and then analyze them!

Representations in Juggling: Ladder Notation



Time goes in the direction of the arrow, so read the Ladder diagram from left to right.

The dotted lines which form the rungs of the ladder denote equal time intervals

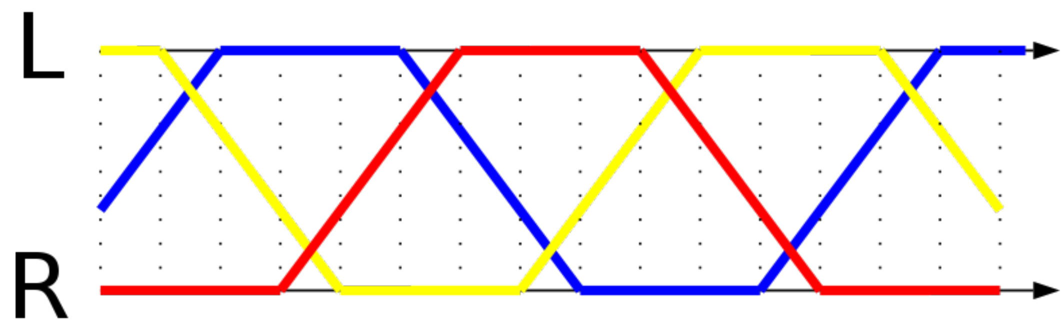
The upper and lower horizontal axis represent “Left Hand” and “Right Hand” respectively

A unique coloured line for each ball with the diagonal lines representing the balls traveling through the air from one hand to the other

http://clubjuggling.com/juggling-notation.html

Example 1

$$\frac{B}{H} = \frac{F + D}{V + D}$$



For the Three-Ball Cascade, we have H = 2 and B = 3, therefore

(F+D)2 = (V+D)3.

The lowest common denominator of 2 and 3 is 6, and 6*2 = 12.

The only option for x*2 = y*3 to be equal to 12 is that x = 6 and y = 4.

This means that the sum of F and D must be 6 and the sum of V and D must be 4, i.e., (3+3)2 = (1+3)3 = 12.

https://commons.m.wikimedia.org/wiki/File:Juggling_Shannon%27s_theorem_Cascade.png

Example 1 (cont'd)

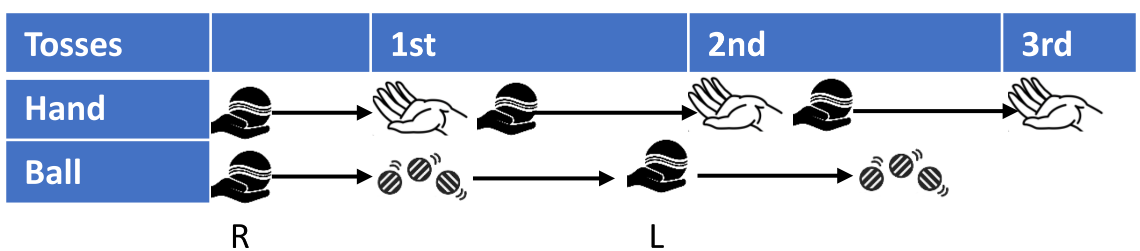
Since there are only three balls, the only options for D in (V+D)3 = 12 are either 1, 2 and 3, corresponding to:

If D = 1 then F must equal 5 and V must equal 3. (5+1)2 = (3+1)3 = 12

If D = 2 then F must equal 4 and V must equal 2. (4+2)2 = (2+2)3 = 12

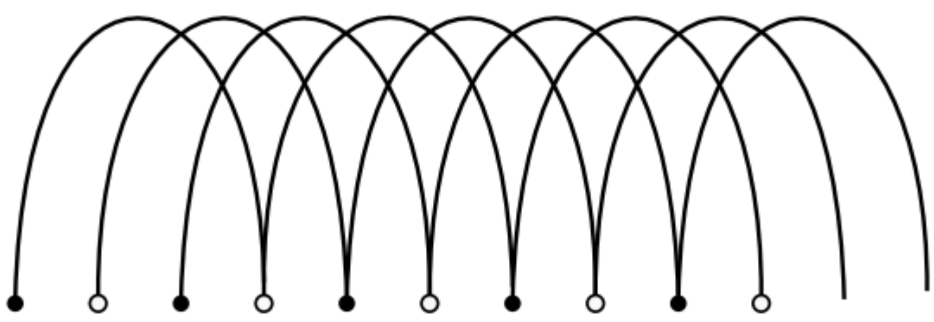
If D = 3 then F must equal 3 and V must equal 1. (3+3)2 = (1+3)3 = 12

Can you draw the Ladder notations for each of these possibilities?



Representations in Juggling: Siteswap

- Balls are juggled in a constant beat, i.e., throws occur at discrete equally-spaced slots in time
- Juggling patterns are periodic
- At most one ball gets caught and thrown at every beat
- Siteswap invented by Paul Klimek in 1981, developed later in 1985 by Bruce Tiemann and other jugglers and mathematicians as a *knowledge representation* for juggling



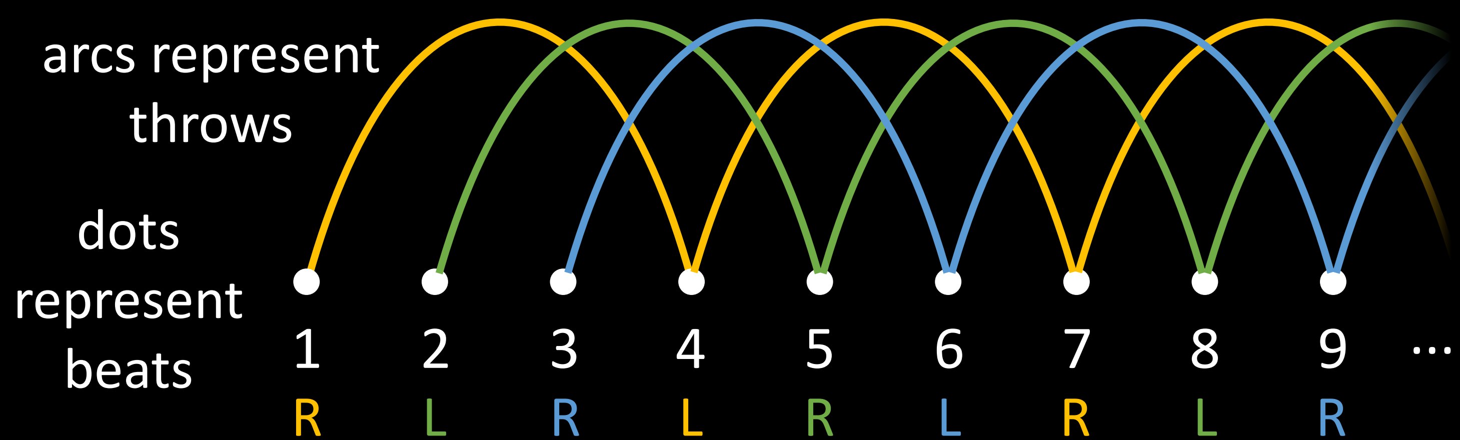
https://en.wikipedia.org/wiki/Siteswap

Basic Juggling Patterns

Axioms:

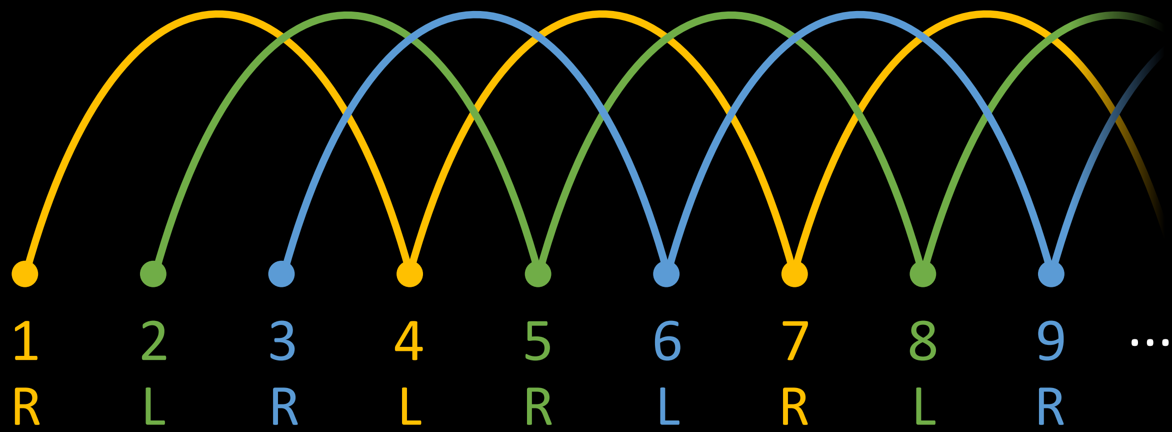
1. The juggler must juggle at a **constant rhythm**.
2. Only **one** throw may occur on each beat of the pattern.
3. Throws on odd beats must be made from the right hand; throws on even beats from the left hand.
4. The pattern juggled must be **periodic**. It must repeat. It must repeat.
5. All balls must be thrown to the **same height**.

Example: basic 3-ball pattern (illustrated by a **juggling diagram**)



Here, all throws are **3-throws**.

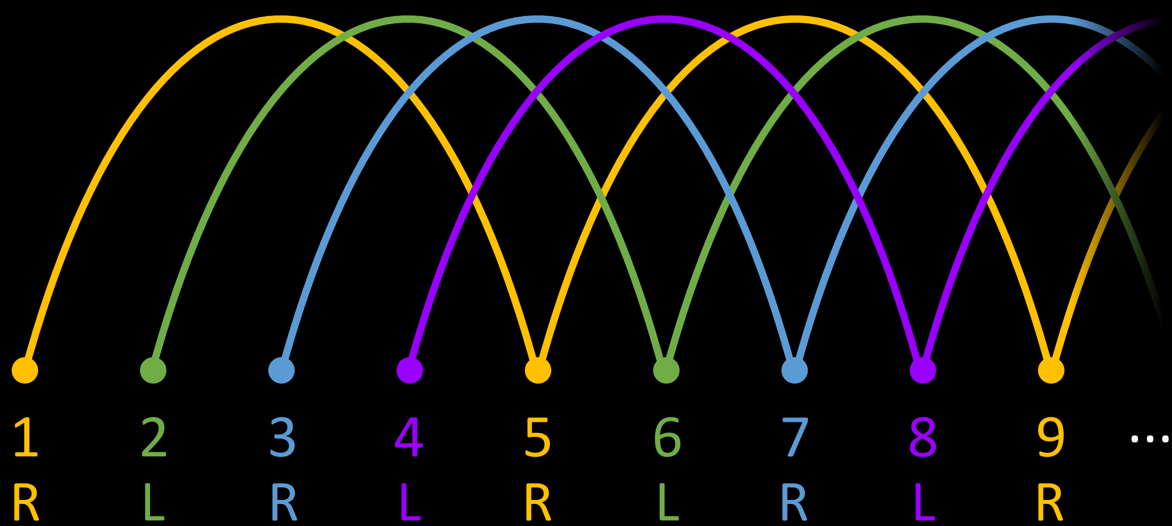
Basic 3-ball Pattern



All throws are **3-throws**.

Balls land in the **opposite** hand from which they were thrown.

Basic 4-ball Pattern



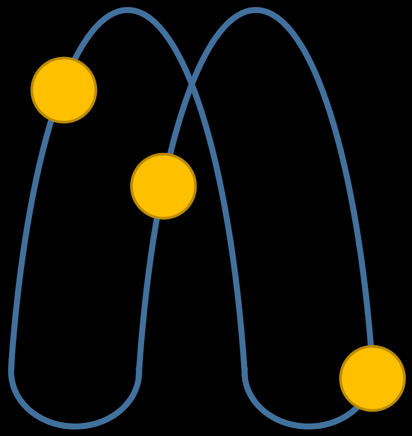
All throws are **4-throws**.

Balls land in the **same** hand from which they were thrown.

The Basic b-ball Patterns

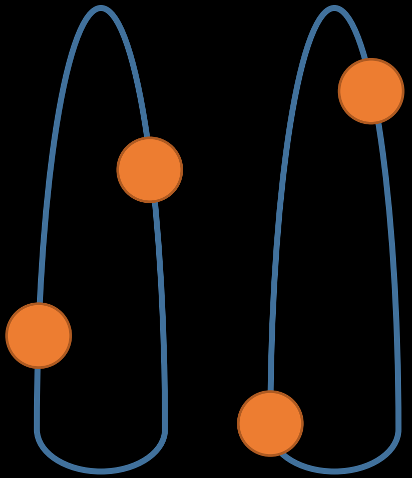
If b is odd:

- Each throw lands in the opposite hand from which it was thrown.
- These are called **cascade** patterns.



If b is even:

- Each throw lands in the same hand from which it was thrown.
- These are called **fountain** patterns.



Let’s change things up a bit…

Axioms:

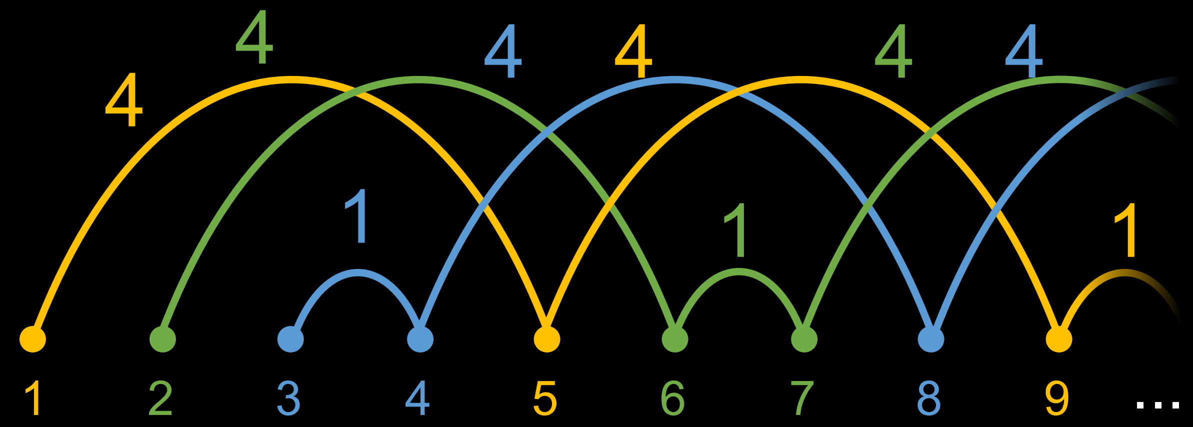
1. The juggler must juggle at a **constant rhythm**.
2. Only **one** throw may occur on each beat of the pattern.
3. Throws on even beats must be made from the right hand; throws on odd beats from the left hand.
4. The pattern juggled must be **periodic**. It must repeat. It must repeat.
5. ~~All balls must be thrown to the **same height**.~~

What if we allow throws of *different* heights?

Axioms 1-4 describe the **simple juggling patterns**.

Example

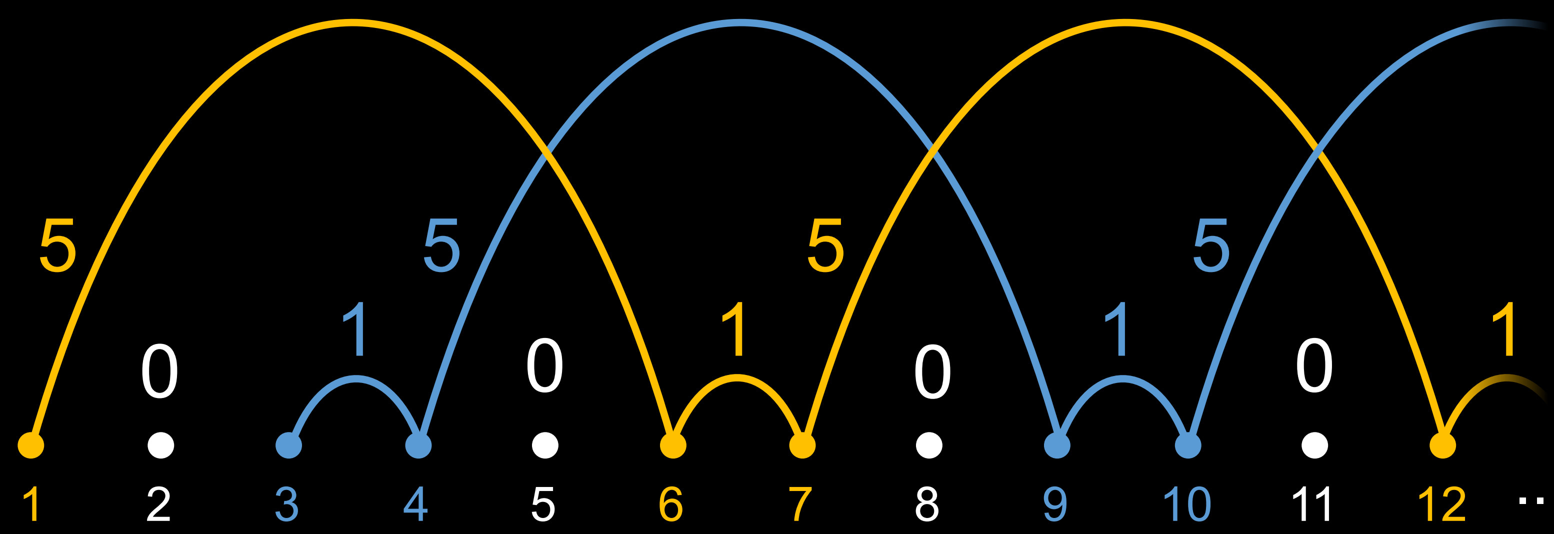
We can make a 4-throw, then a 4-throw, then a 1-throw, and repeat:



We call this pattern **4, 4, 1** (often written **441**).

This is an example of a **juggling sequence**: a (finite) sequence of nonnegative integers corresponding to a simple juggling pattern.

The sequence **501** is a juggling sequence:



This sequence is juggled with only two balls!

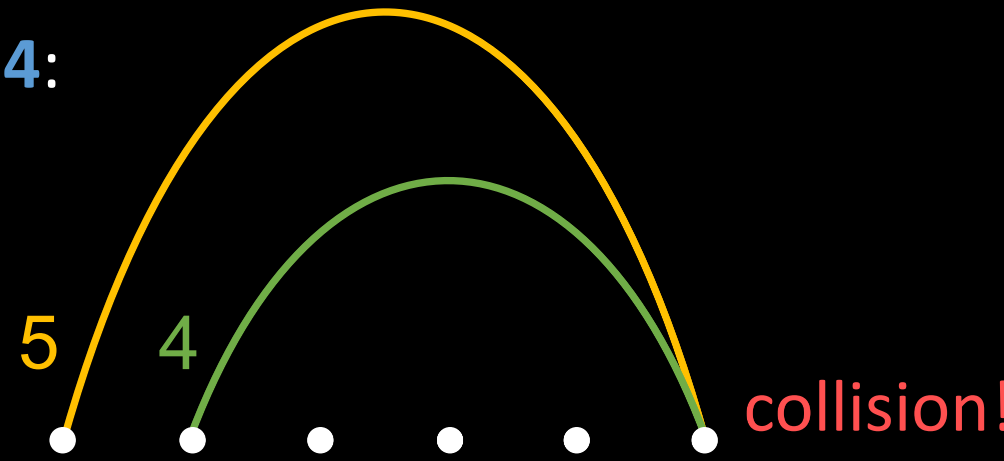
The **period** of this sequence is 3.

This sequence is **minimal**, since it has the smallest period among all juggling sequence that represent this pattern.

Is every nonnegative integer sequence a juggling sequence?

No.

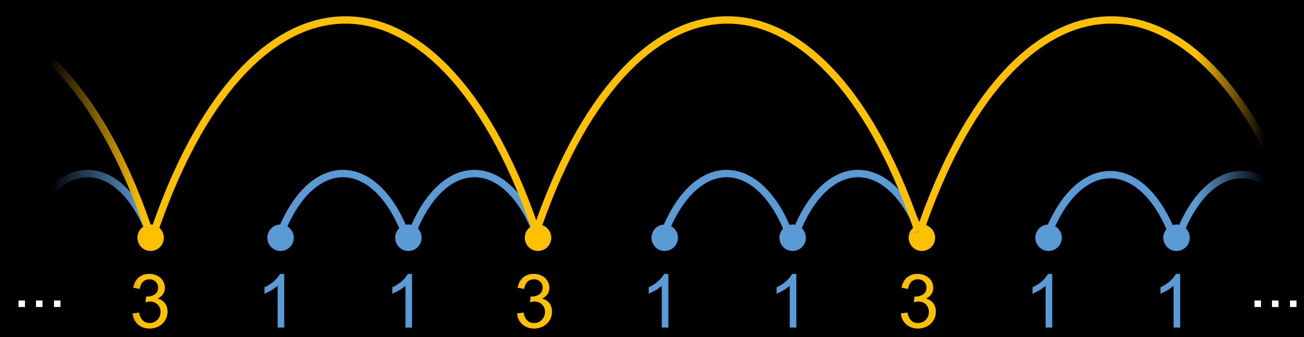
Consider the sequence **54**:



A 5-throw followed by a 4-throw results in a collision.

In general, an n-throw followed by an $(n-1)$-throw results in a collision.

The sequence **311** is not a juggling sequence.



How can we tell if a sequence is a juggling sequence?

Draw its juggling diagram and check that:

a. At each dot, either exactly one arch ends and one starts, or no arches end and start; and

b. All dots with no arches correspond to 0-throws.

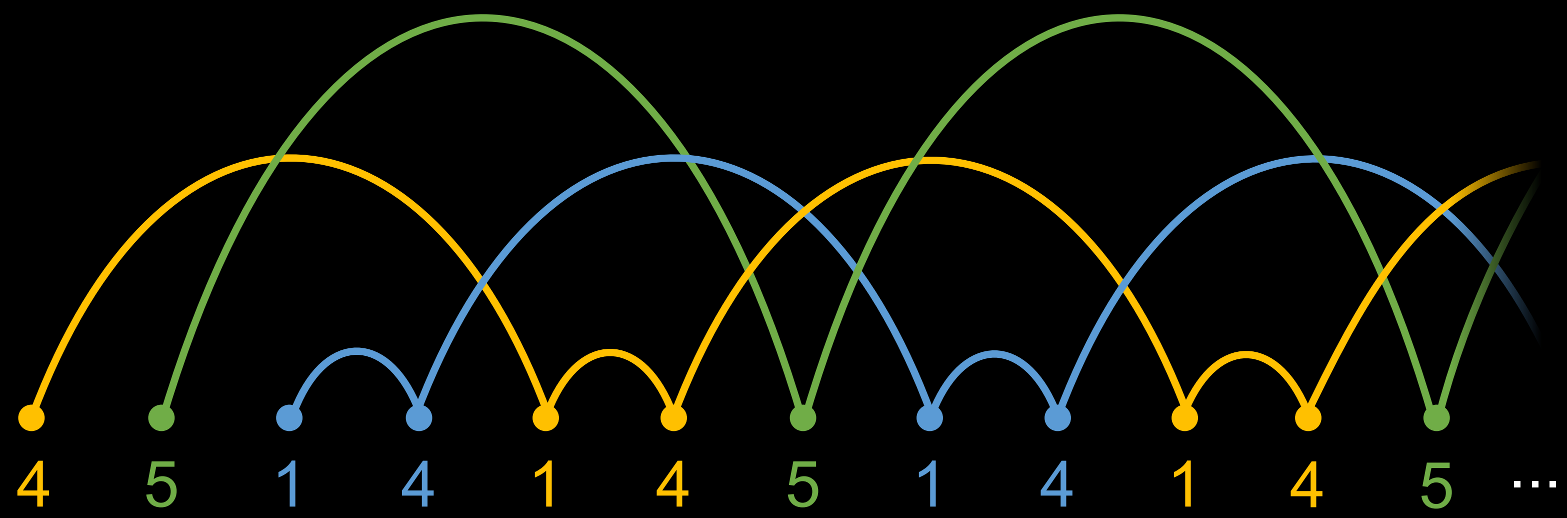
Examples of Juggling Sequences

2-balls: **31**, **312**, **411**, **330**, **501**

3-balls: **441**, **531**, **51**, **4413**, **45141**

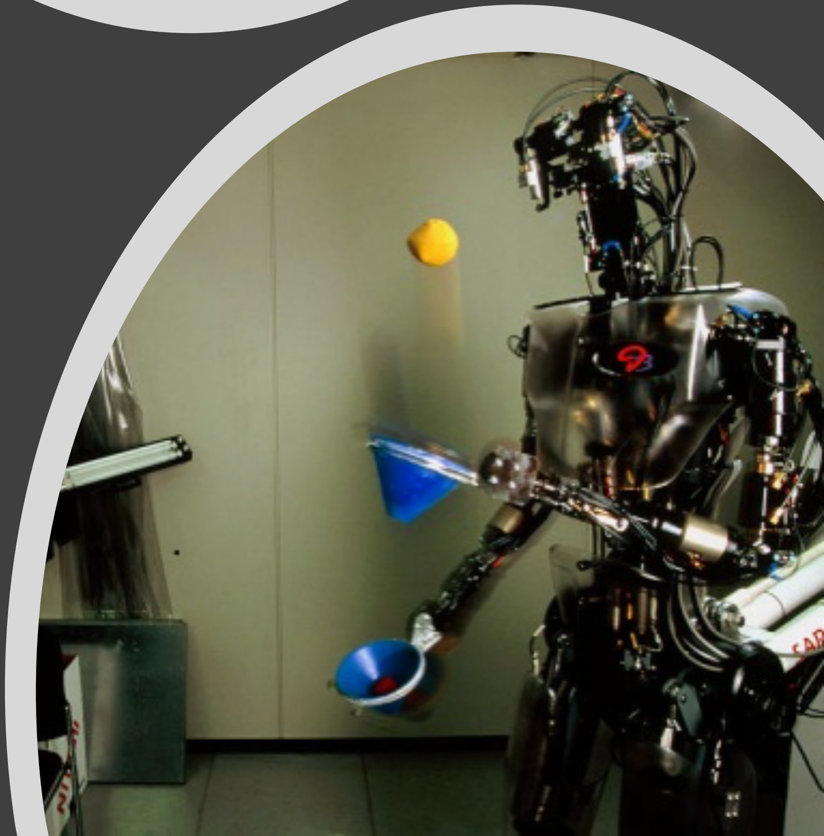
4-balls: **5551**, **53**, **534**, **633**, **71**

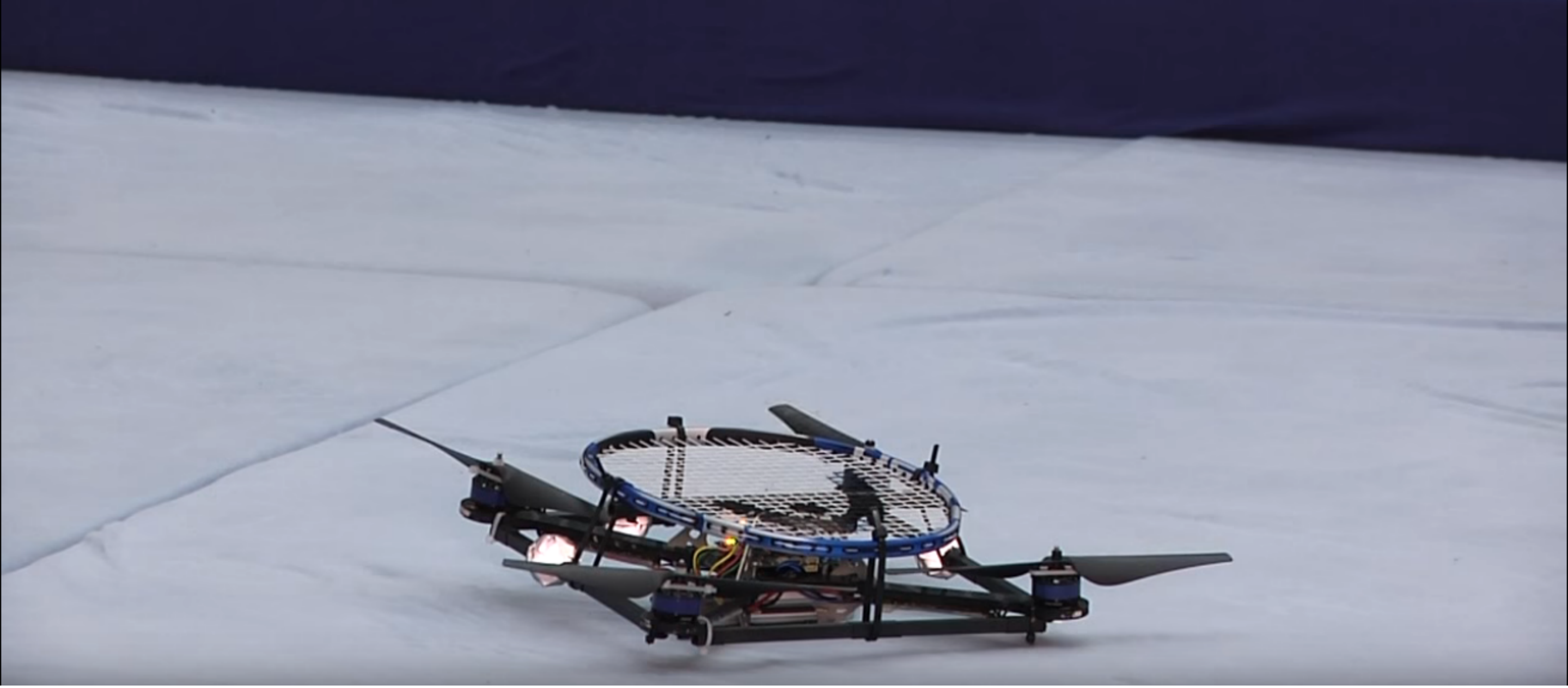
5-balls: **66661**, **744**, **75751**



AI Robot: Juggling Machines

- Claude Shannon Juggling
- Shannon Juggling Machine
- Movement Act Machine
- Quadrocopter Ball Juggling by ETH Zurich
- Roboseum: A Museum of Robot Juggling
- Amazon Warehouse Robots





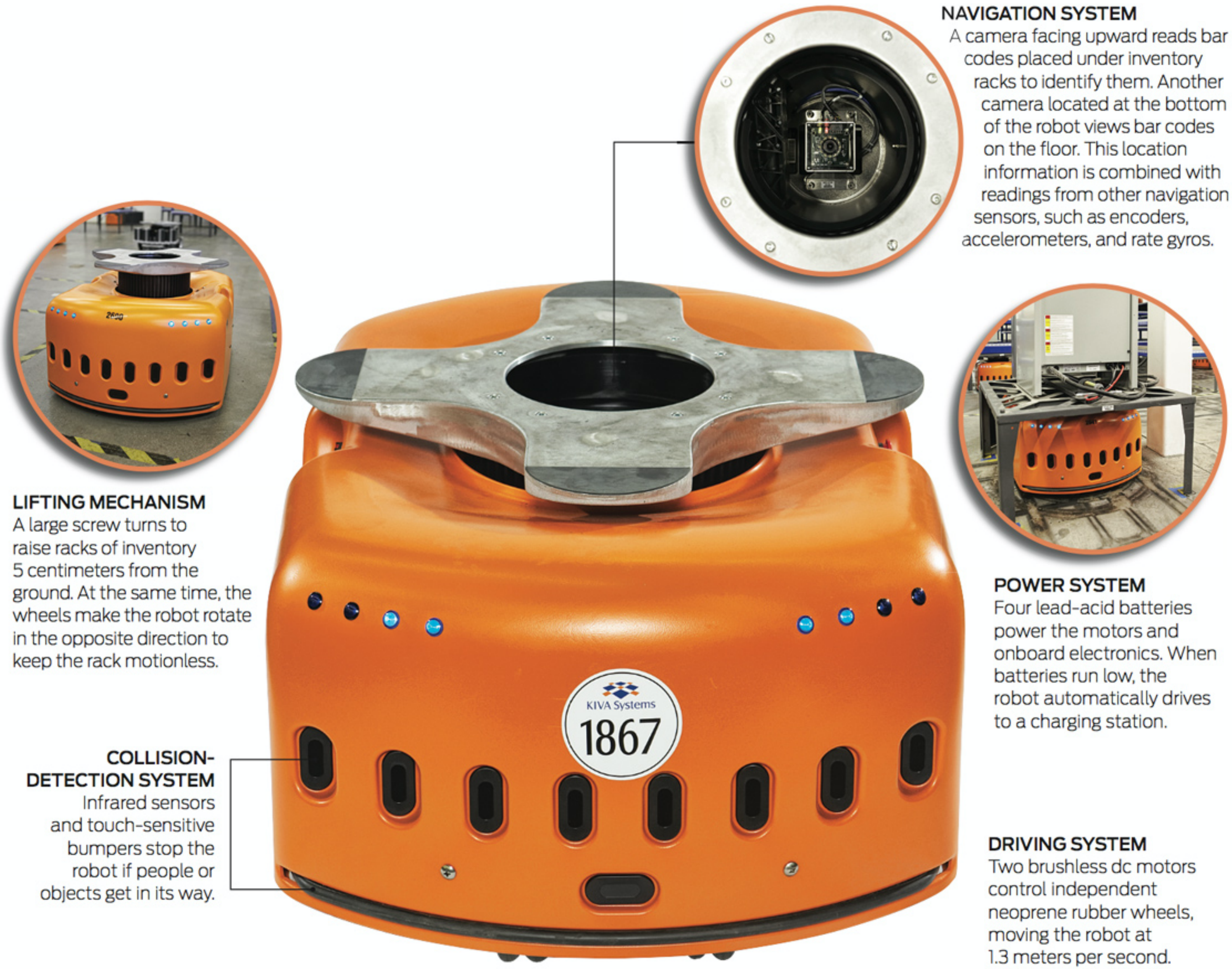
Quadrocopter Ball Juggling

- ETH Zurich Institute for Dynamic Systems and Control
- https://www.youtube.com/watch?v=3CR5y8qZf0Y

Amazon Warehouse Robots

https://www.youtube.com/watch?v=cLVCGEmkJs0

Amazon Robotics/Kiva's Robots



https://spectrum.ieee.org/image/MzE0MTE4Ng.jpeg

Amazon Robotics/Kiva's Robots

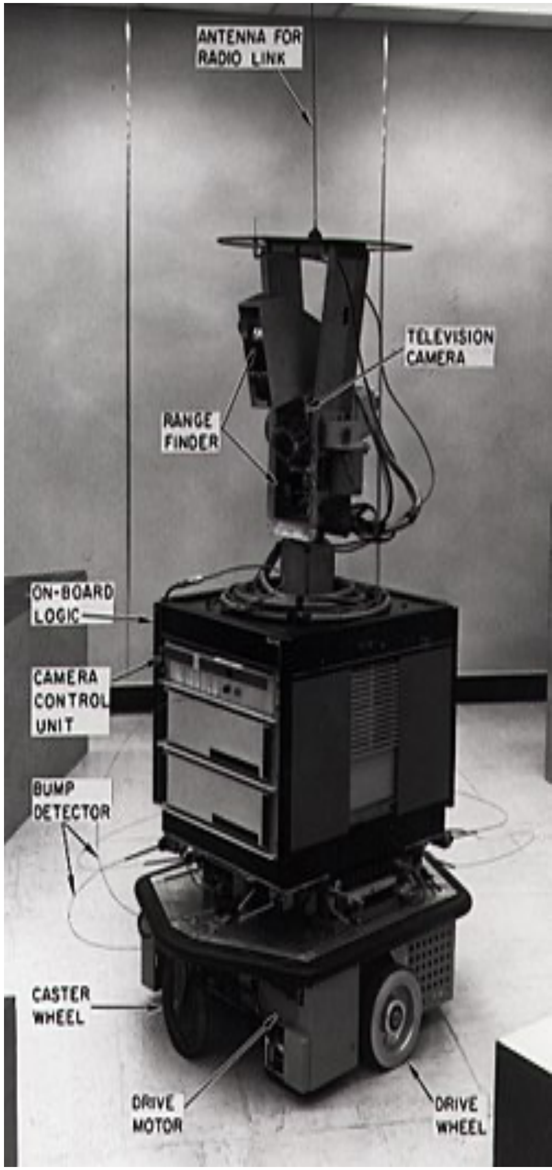
- The robots navigate the warehouse by pointing cameras at the floor to read two-dimensional bar-coded stickers laid out by hand 1 meter from each other, in a grid.
- The robots relay the encoded information wirelessly to a computer cluster that functions both as a dispatcher and a traffic controller.
- It instructs, for instance, robot No. 1051 to bring rack No. 308 to worker No. 12—without colliding with robot No. 1433, which is crossing its path.
- It also shares that information with other robots. This distributed-control approach improves their navigation capabilities. Say a robot sees certain stickers off to the left. Instead of simply correcting its course by turning to the right, the robot first checks what other robots see—what the "wisdom of the crowd" is. The robot then adjusts its own control parameters to navigate more accurately.

https://www.google.com/url?sa=i&url=https%3A%2F%2Fmakeagif.com%2Fgif%2Famazon-warehouse-kiva-robots-RRQHF7&psig=AOvVaw2xCQyZ2pjW2pb-wxN8v90E&ust=1573018497118000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCPi33tis0uUCFQAAAAAdAAAAABAJ

Shakey The Robot at Stanford (1970)

The world's first mobile intelligent robot!

- Developed at the Stanford Research Institute (SRI)
- Actions:
  - ➢ Moving around
  - ➢ Climbing up and down from objects
  - ➢ Pushing movable objects
  - ➢ Opening and closing the doors
  - ➢ Turning the light switches on and off



B. Raphael, The Thinking Computer, Chapter 8 Robots