Manipulators for FIRST FRC Robotics

FIRST Fare 2017

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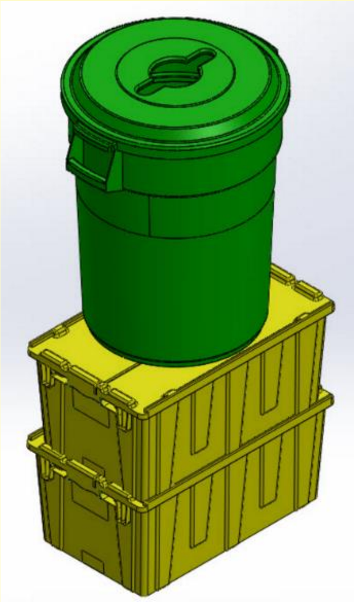
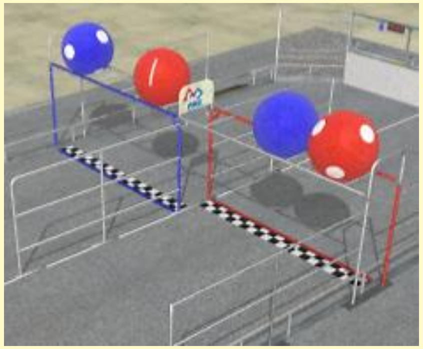
Mentor, Team 2471

Manipulate What ?

- Game pieces come in many sizes and shapes





Manipulate How ?

Game objectives change each year

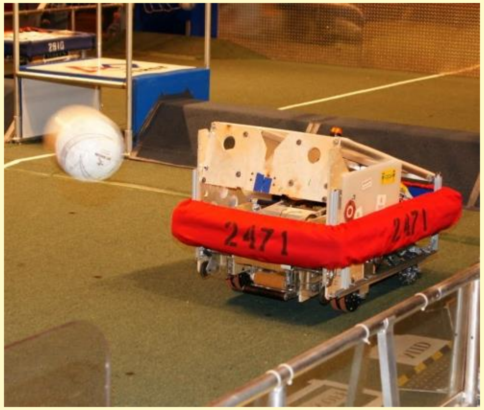
Lift

Dump

Hang

Stack

Kick



Gather

Throw

Fling

Where to Start ?

Know the Objectives

Read game & robot rules

Define your game strategy

Test the game pieces

Learn what works

Look on line

Talk to mentors

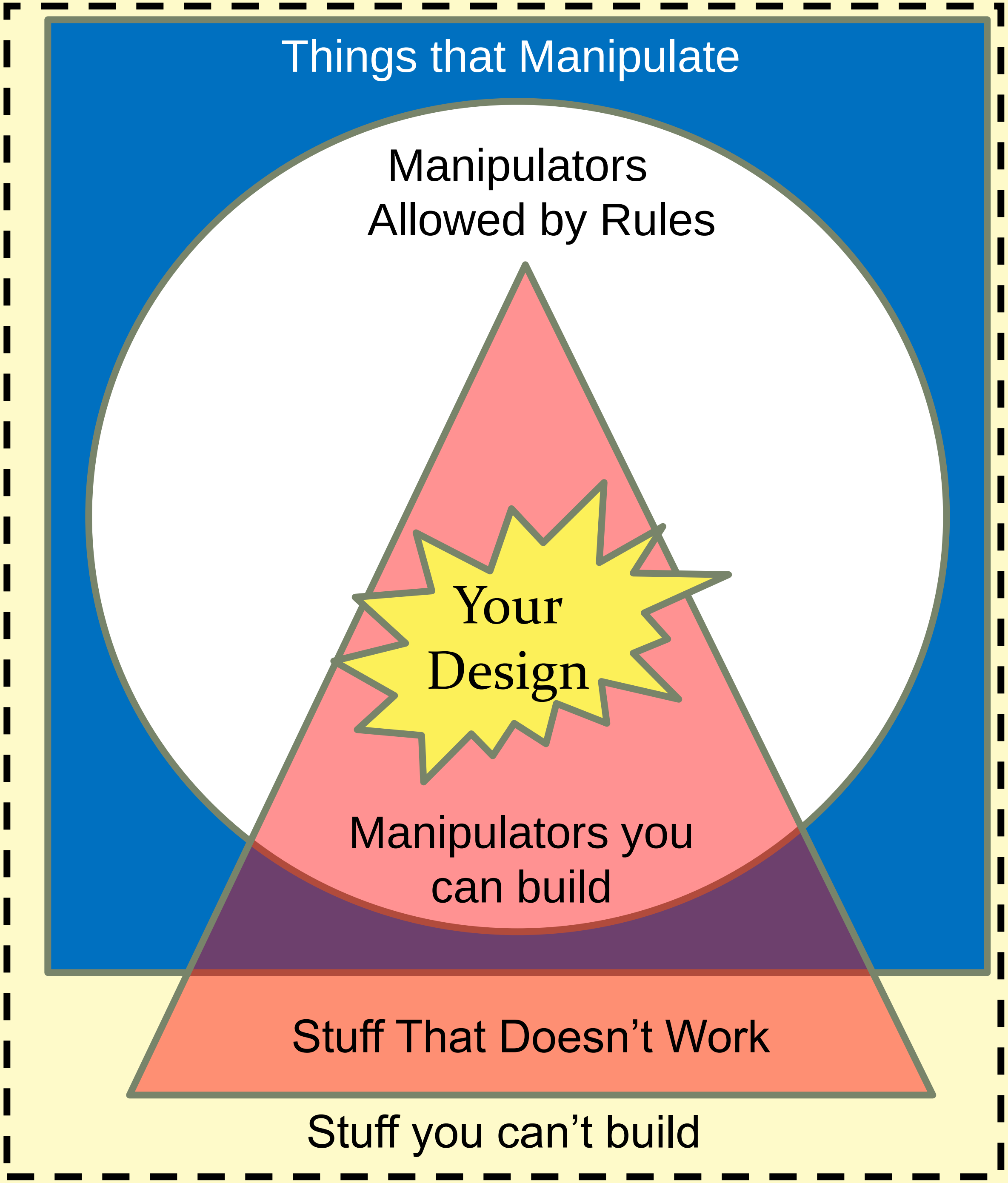
Talk to other teams

Understand your capability

Tools & Skills,

Materials, Manpower

Budget, Time



FIRST Definition of a Manipulator

A device that moves the game piece from where it is to where it needs to be.

Reoccurring Themes

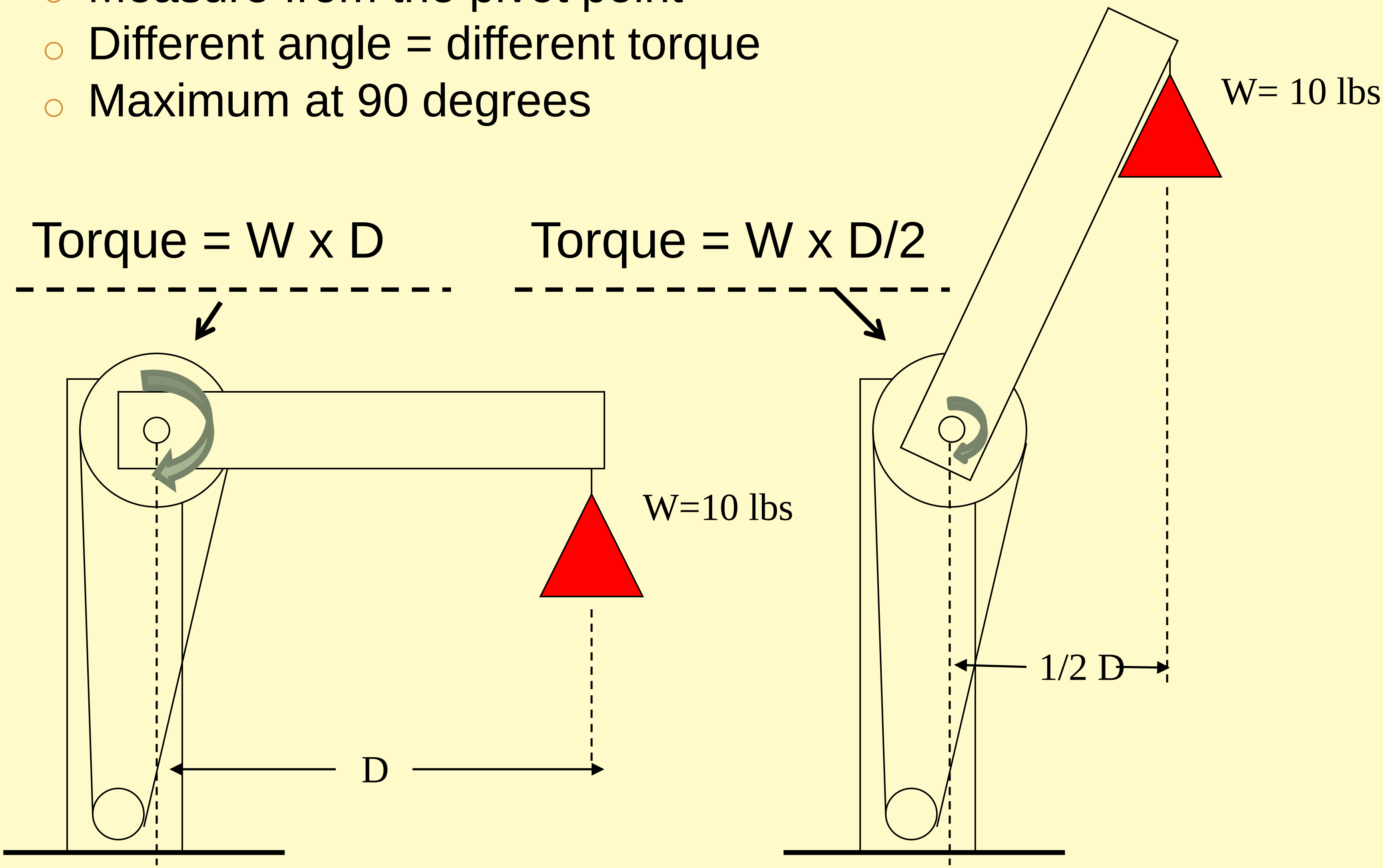
- Lift & Reach
  - Articulating Arms
  - Parallel arms
  - Telescoping Lifts
- Grab & Grip
  - Rollers
  - Clamps
  - Claws
- Collect and Deliver
  - Conveyers
  - Turrets
  - Shooters
  - Kickers
  - Buckets
- Climb and Winch
  - Winches
  - Brakes
  - Latches
  - Pneumatics
  - Springs / Bungee
  - Gears & Sprockets

Arms

Shoulder
Elbow
Wrist

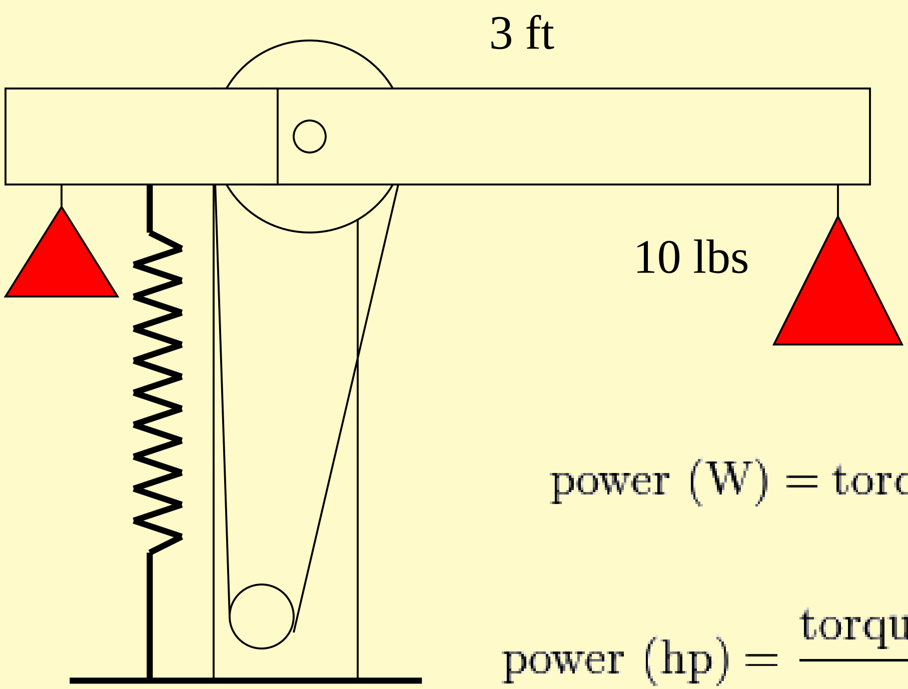
Torque & Weight limits arm length.

- Torque = Force x Distance
  - Measure from the pivot point
  - Different angle = different torque
  - Maximum at 90 degrees



Power & Torque Limit Speed

- Power determines how fast you can move things
- Power = Torque / Time or Torque x Rotational Velocity
- Counter weight or springs can help



$$\text{power (W)} = \text{torque (N} \cdot \text{m)} \times 2\pi \times \text{rotational speed (rps)}$$

$$\text{power (hp)} = \frac{\text{torque(lbf} \cdot \text{ft)} \times 2\pi \times \text{rotational speed (rpm)}}{33000}.$$

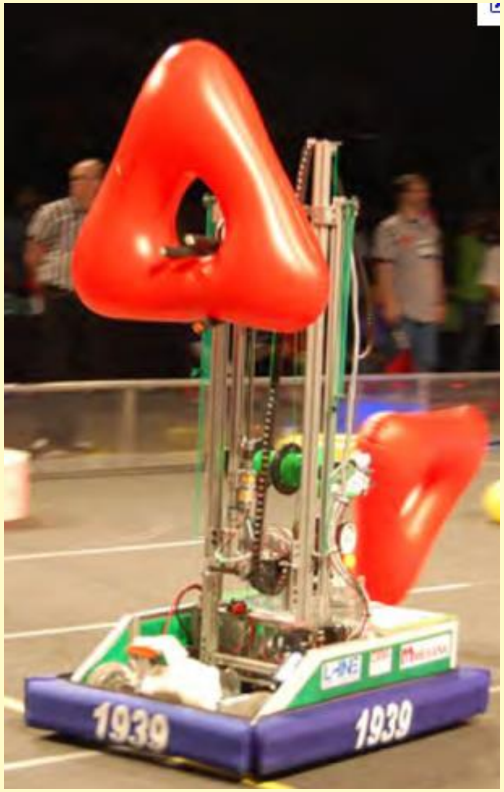
Arm Design Tips

- Lightweight Materials:
  - Thin wall tubes, lightening holes
  - Concentrate weight near pivot
- Use sensors for feedback & control
  - Limit switches
  - Potentiometers
  - Encoders
- Keep it stiff
- Use counterbalances
  - Spring, weight, pneumatic, bungee…
- Calculate the forces
  - Check for center of gravity
  - May tip when arm is extended
- Model reach & orientation
- KISS your arms
  - Less parts to build. Less parts to break

Dr. Claw in 2014

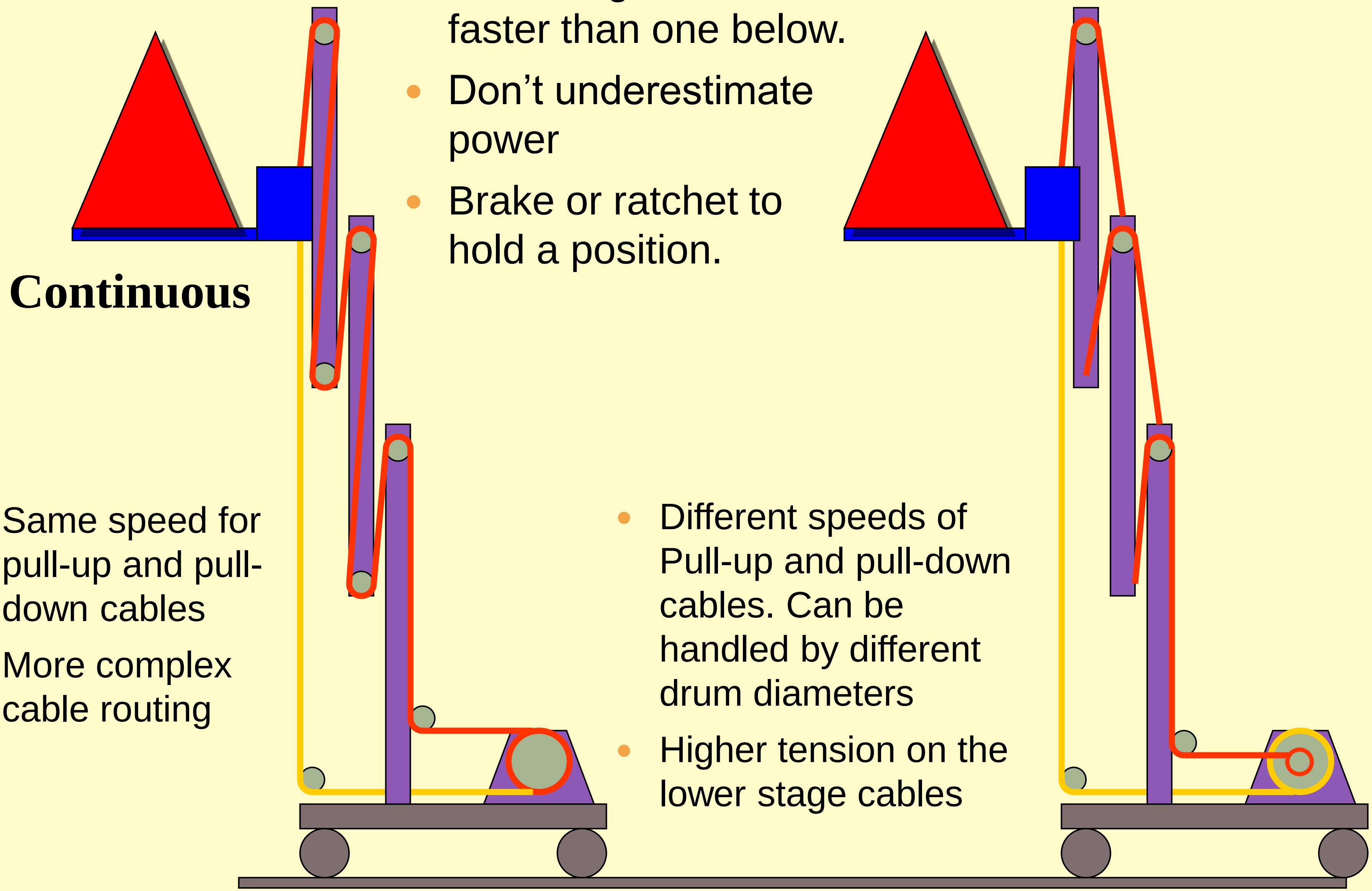
Telescoping Lifts

- Scissor Lift
  - Motion achieved by “unfolding” crossed members
  - High stress loads at beginning of travel (spring assist can start movement)
  - Difficult to build well. Not recommended without prior experience.
- Extension Lifts
  - Motion achieved by stacked members sliding on each other



Extension Lift Rigging

- Each stage moves faster than one below.
- Don't underestimate power
- Brake or ratchet to hold a position.

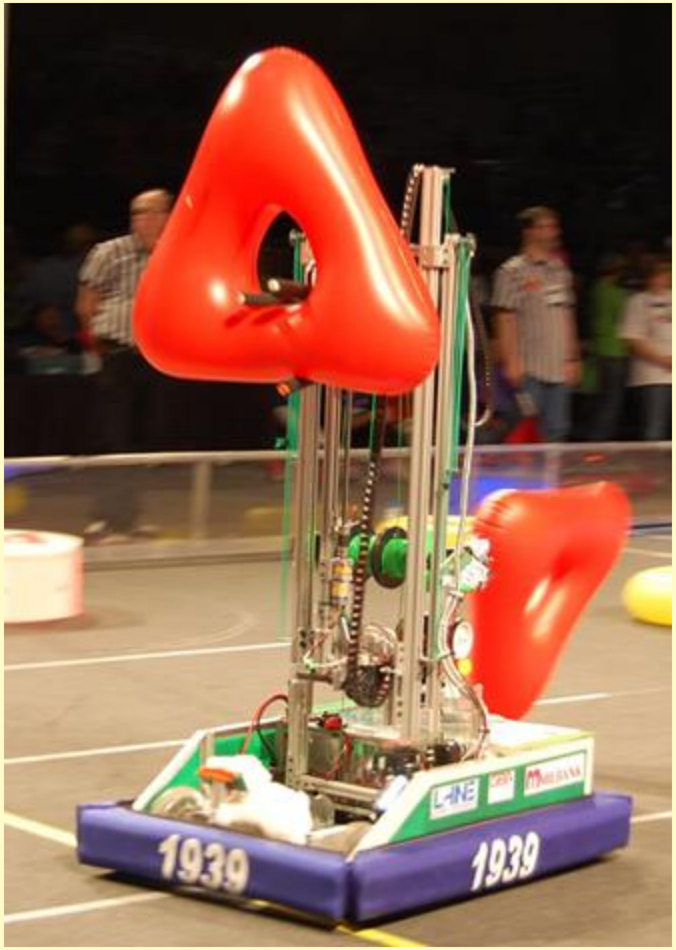


- Same speed for pull-up and pull-down cables
- More complex cable routing

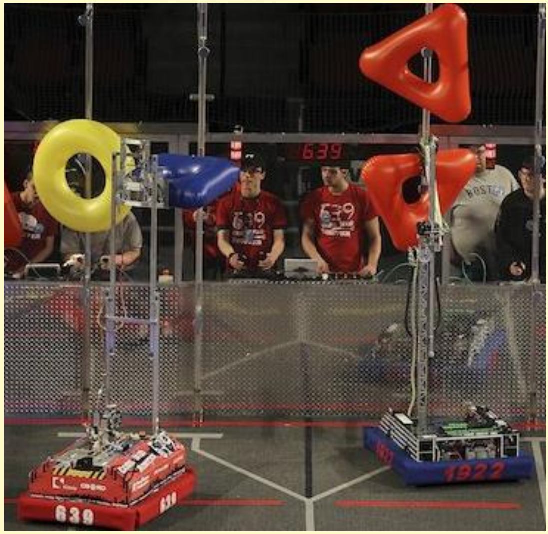
- Different speeds of Pull-up and pull-down cables. Can be handled by different drum diameters
- Higher tension on the lower stage cables

Extension Lift Design tips

- Drive both *<u>and down</u>*, or add a return spring.
- Segments must move freely
- Minimize slop and free-play
- Segment overlap for stability
  - 20% minimum
  - More for bottom, less for top
- Stiffness and strength needed
- Minimize weight, especially at top



Arms vs. Lifts



Feature	Arm	Lift
Reach over object	Yes	No *
Get up after tipping	Perhaps, if strong	No
Complexity	Moderate	High
Weight capacity	Moderate	High
Go under barriers	Yes, folds down	Maybe, limits lift height
Center of gravity	Cantilevered	Central mass
Operating space	Large swing space	Compact
Adding reach	More articulations	More lift sections
Combinations	Arm with extender	Lift with arm on top

Get a Grip

FIRST definition of a gripper:

Device that grabs a game object

…and releases it when needed.

Design Concerns

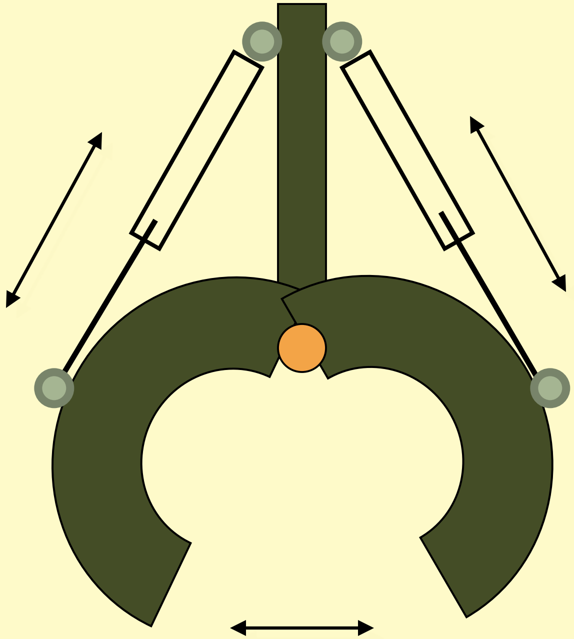
- Getting object into grip
- Hanging on
- Speed of grip and release
- Position control
- Location of weight
  - Especially if at end of arm

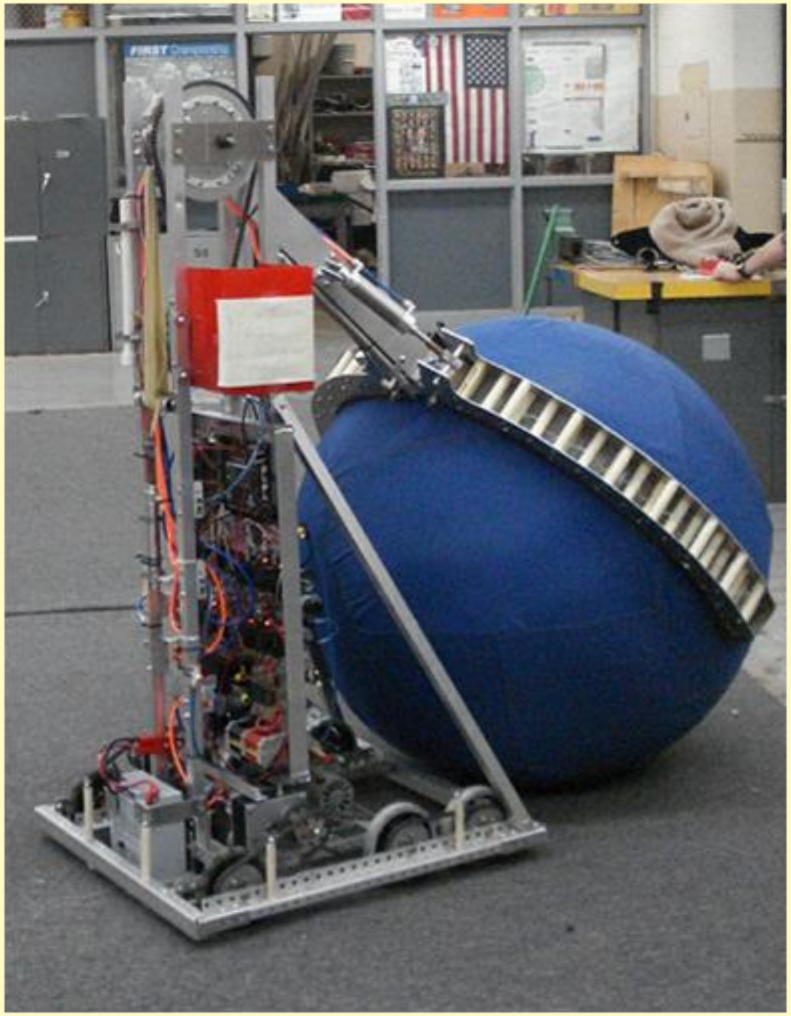
Lot of Methods

- Pneumatic claws /clamps
  - 1 axis
  - 2 axis
- Motorized claw or clamp
- Rollers
- Hoop grips
- Suction

Claw or clamp

- Pneumatic
- One fixed arm
- Hollow claw to reduce weight
- One or two moving sides



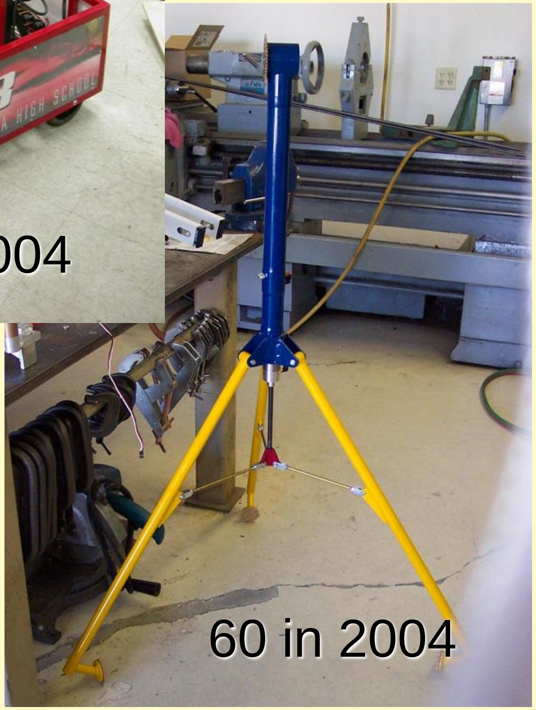


768 in 2008

Pneumatic: 2 and 3 point clamps

- Pneumatic Cylinder extends & retracts linkage to open and close gripper
- Combined arm and gripper
- Easy to make
- Easy to control
- Quick grab
- Limited grip force
- Use 3 fingers for 2-axis grip

968 in 2004

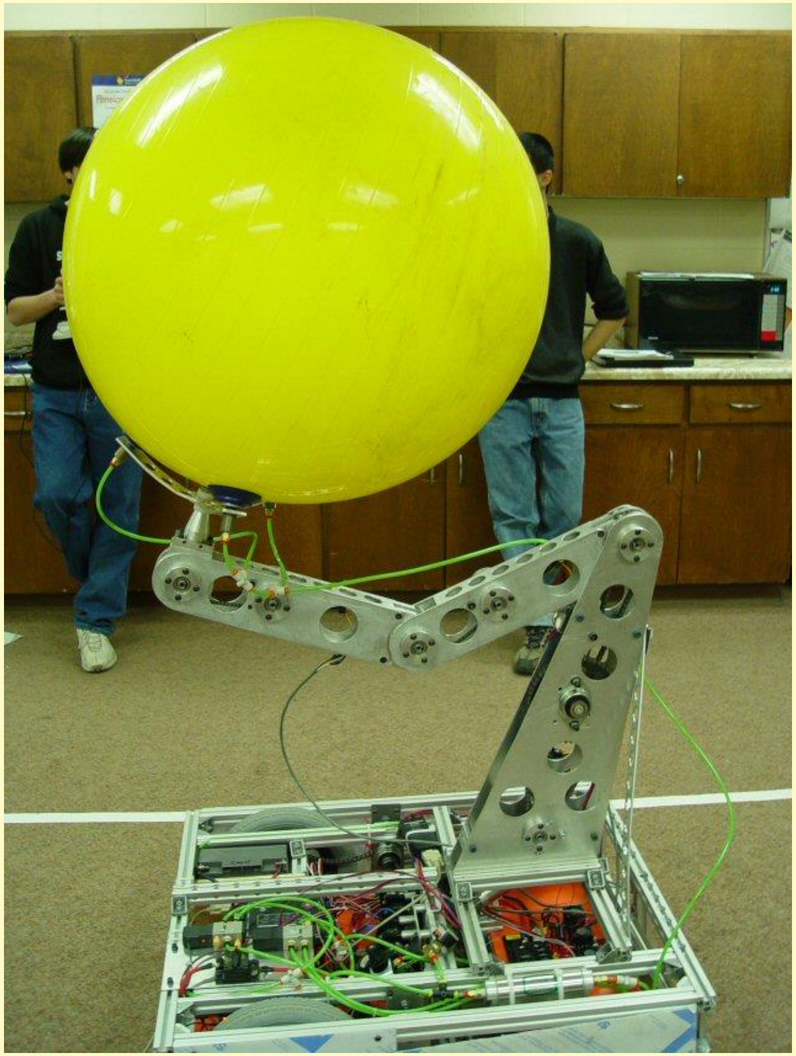

60 in 2004

Motorized clamp

- Generally slower
  - Not good for frequent grabs
  - Okay for a few grabs per game or heavy objects
- More complex and heavier
  - Due to gearing & motors
- Tunable force
- No pneumatics

49 in 2001

Suction Grips



- Needs vacuum generator
- Suction cups to grab
- Requires precise placement.
  - No grab until a seal is made
  - May fail if suction cup is damaged

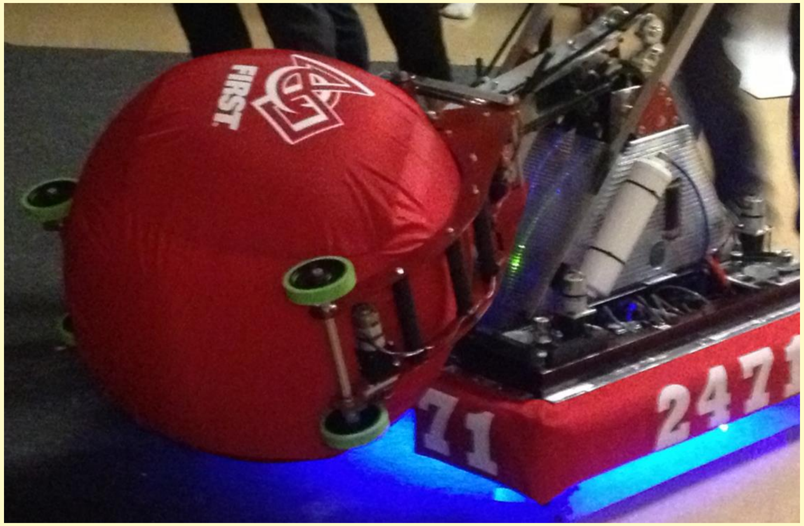
Not recommended for heavy or irregular game pieces

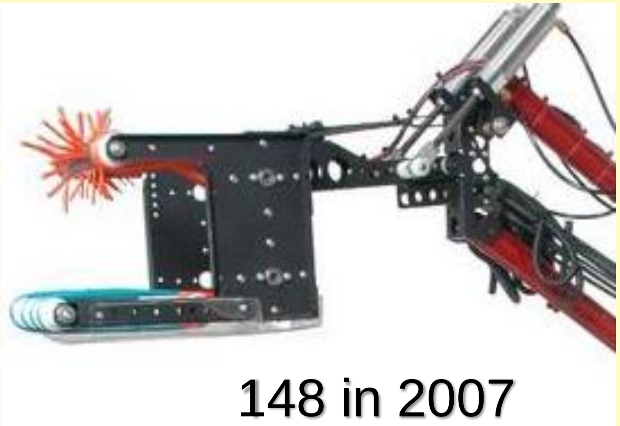
Used effectively to hold soccer balls in place for kickers

(Breakaway 2010)

Roller Grips

- Allows for misalignment when grabbing
- Won't let go
- Extends object while releasing
- Simple mechanism
- Use sensors to detect position.
- Many variations
  - Mixed roller & conveyer
  - Reverse top and bottom roller direction to rotate object

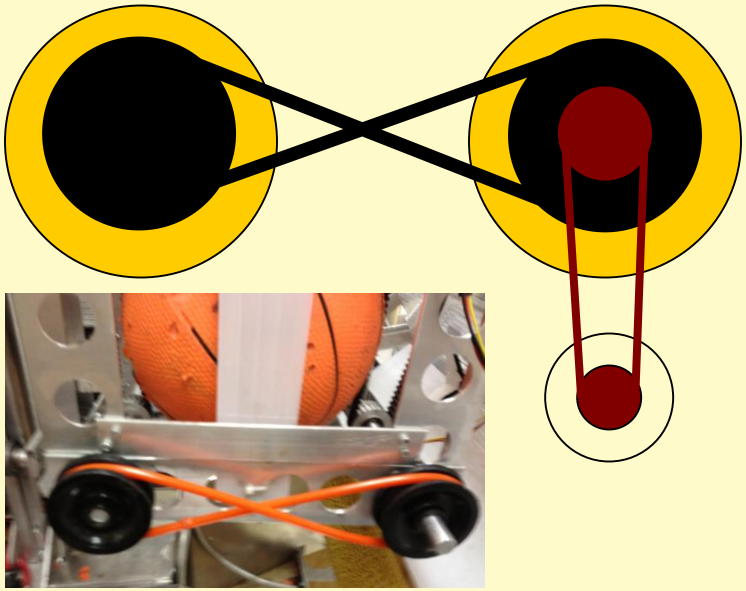




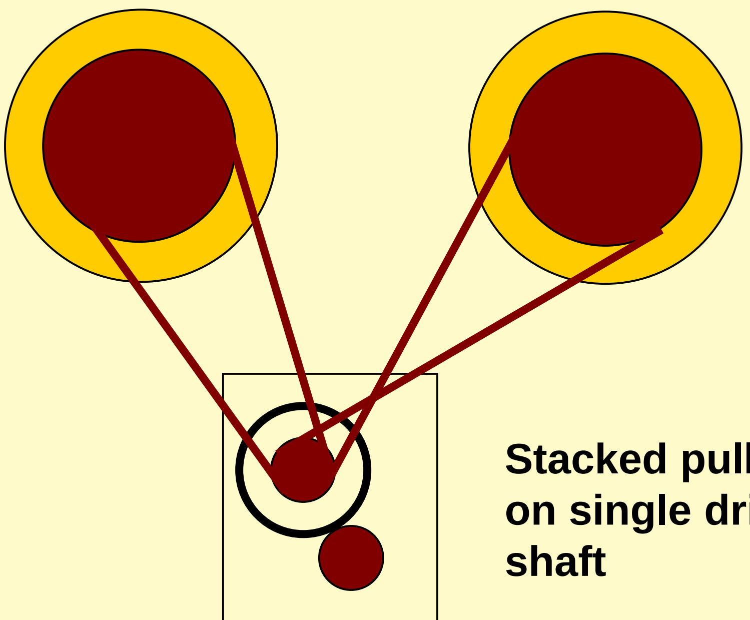
148 in 2007

Counter Rotating Methods

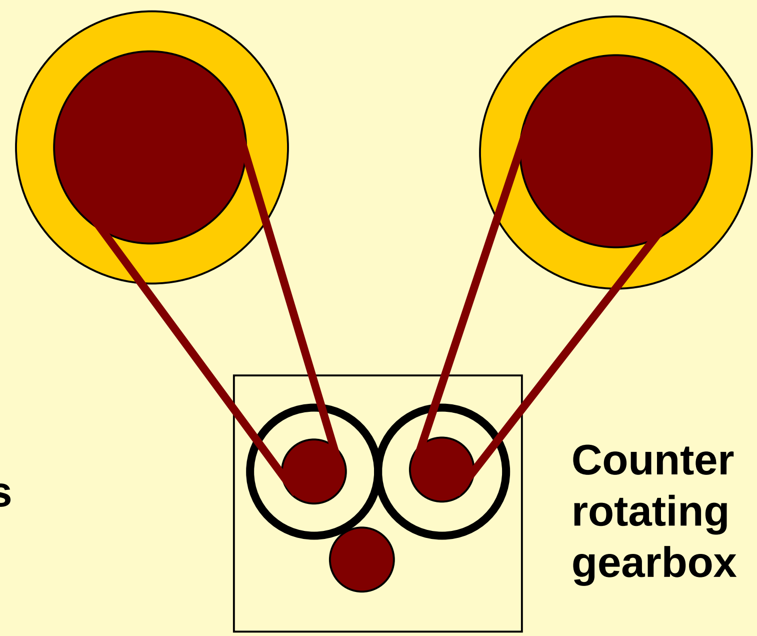
The Infinity Belt



- Many ways to achieve counter rotating shafts. Here are few configurations that can run off a single motor or gearbox.
- Can also drive each side with separate motors



Stacked pulleys on single drive shaft



Counter rotating gearbox

Gripper Design

Hang On!

- High friction surfaces
  - Rubber, neoprene, silicone, sandpaper … but don't damage game pieces
- Force: Highest at grip point
  - 2 to 4 x object weight
- Extra axis of grip = More control buy more complexity

Need for speed

- Wide capture window
- Quickness counts
  - Quick to grab , Drop & re-grab
  - Fast : Pneumatic gripper. Not so fast: Motor gripper
- Make it easy to control
  - Limit switches, Auto-functions
  - Intuitive driver controls

Rotating Turrets

- Tube or post (recommended)
- Lazy Susan (not for high loads)
- Use when appropriate
  - One Goal = good
  - Nine Goals = not so good
  - Fixed targets = good
  - Moving targets = not so good
- Bearing structure must be solid
- Rotating large weights can be slow
- Include sensor feedback
  - Know where its pointing
  - Auto aiming is often needed

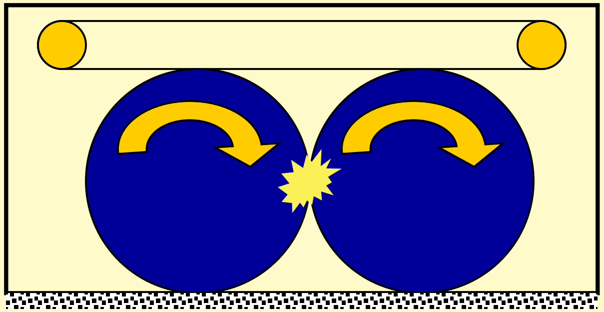
Gathering: Accumulators & Conveyers

Accumulator: Collects multiple objects

- Horizontal rollers: gather balls & other objects from floor
- Vertical rollers: push balls up or down
- Wheels: good for big objects
- Can also use to dispense objects out of robot

Conveyers: Moving multiple objects

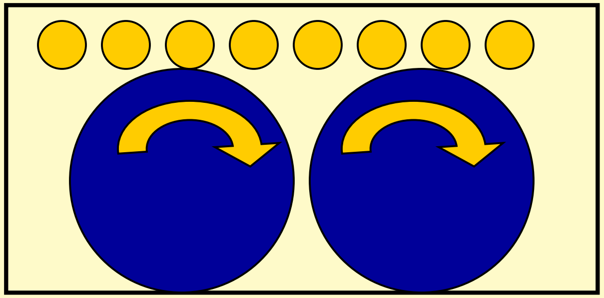
- Moving multiple objects from point A to point B within the robot



1

Why do balls jam on belts?

- Stick and rub against each other as they try to rotate along the conveyor



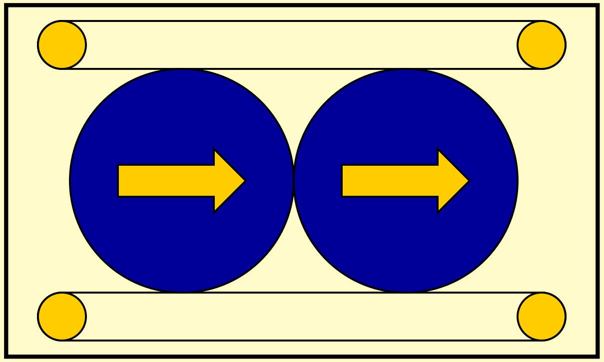
2

Solution #1

- Slippery material for the non-moving surface (Teflon, pebble surface)

Solution #2

- Individual rollers
- Adds weight and complexity



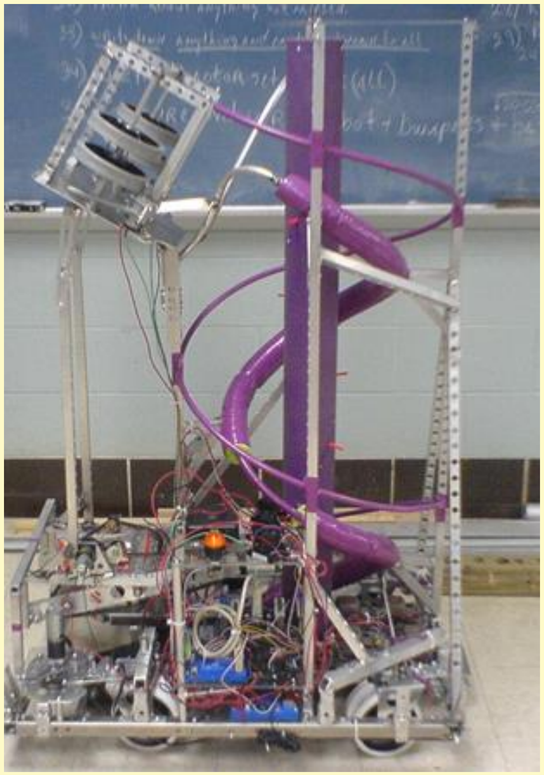
3

Solution #3

- Pairs of belts
- Support against tension

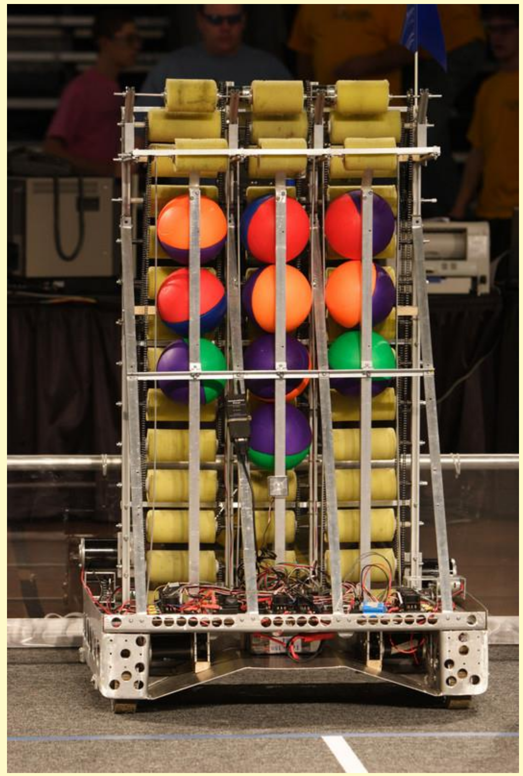
Conveyer Examples

Tower



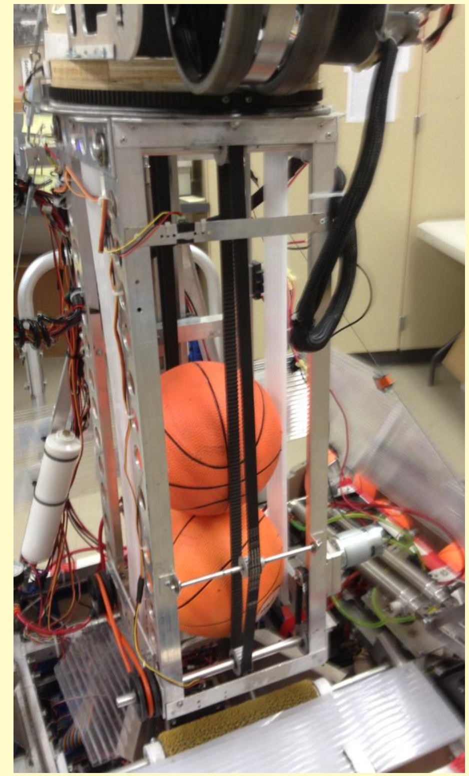
Solution 1

Rollers



Solution 2

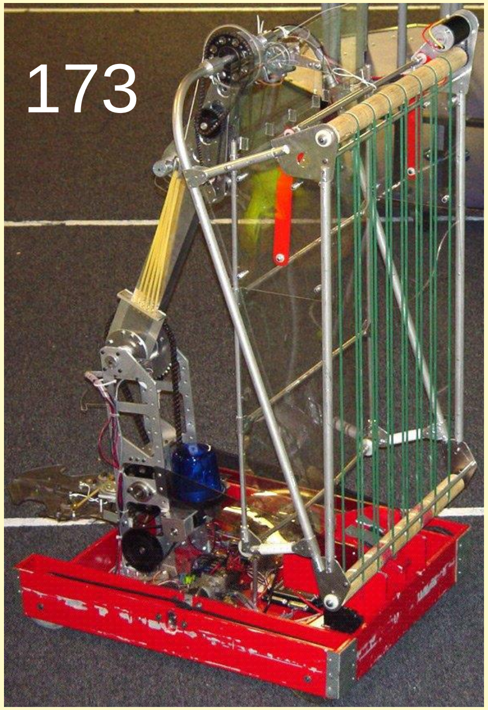
Belts



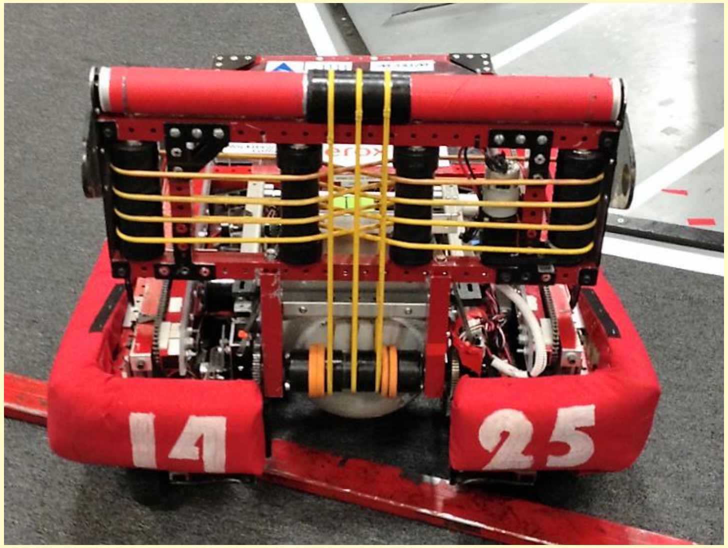
Solution 3

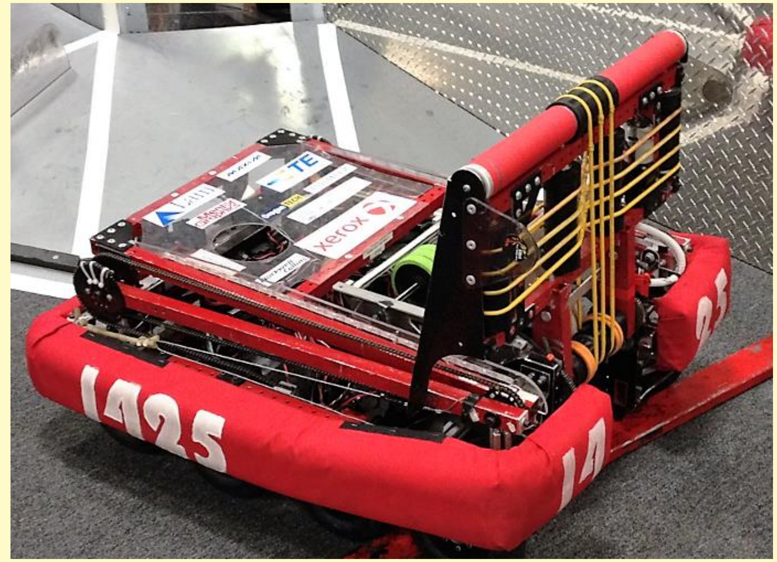
Integrated collector and Accumulator

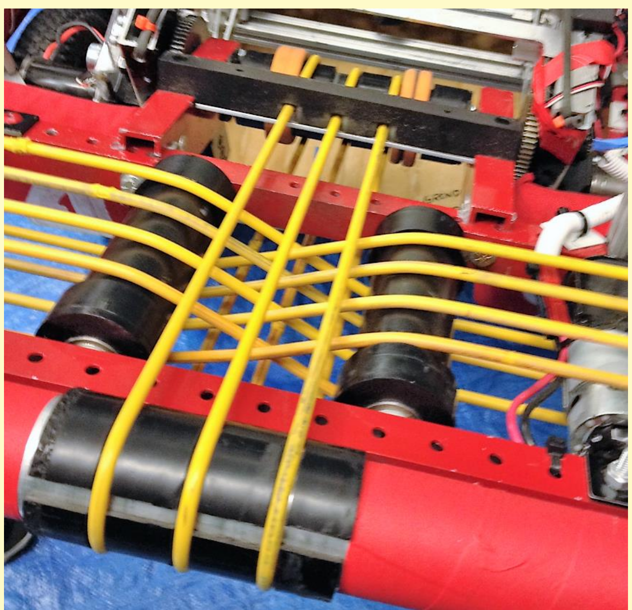
- Control the objects
  - Avoid gravity feeds – Slow and easily jammed
  - Direct the flow. Reduce random movement
- Not all game objects are created equal
  - Variations in size, inflation, etc
  - Build adaptive or adjustable systems
  - Test with different sizes, inflation, etc.

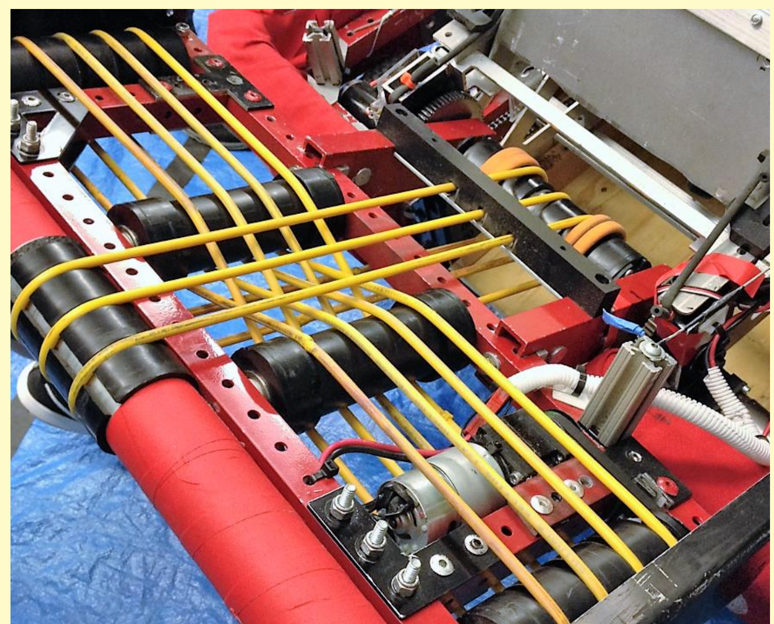


Integrated collector & conveyer









Shooters

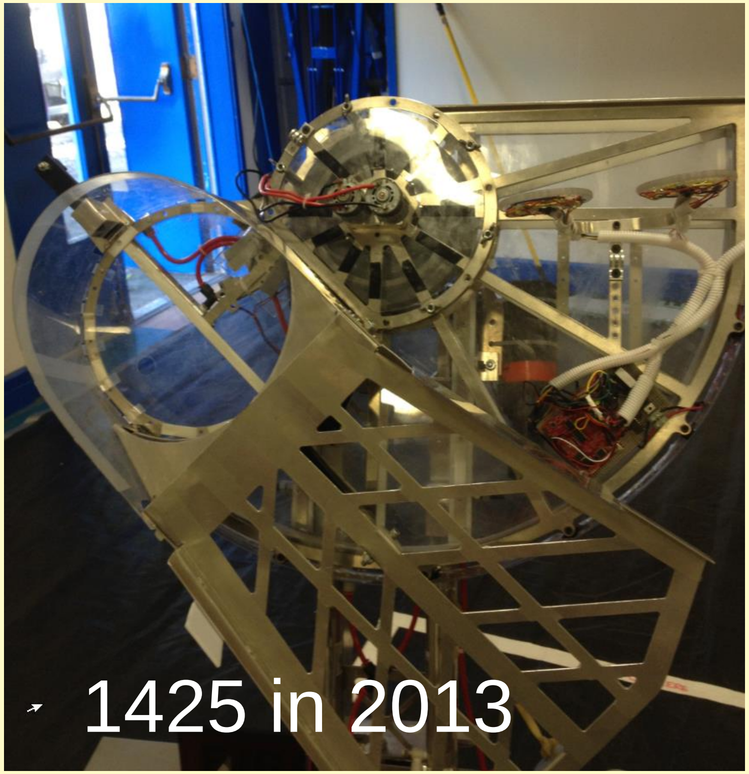
- Secure shooting structure = more accuracy
- Feed balls (or disks) individually, controlling flow
- Rotating tube or wheel
  - One wheel or two counter rotating
  - High speed & power: 2000-4000 rpm
  - Brace for vibration
  - Protect for safety
- Turret allows for aiming
- Sensors detect ball presence & shot direction

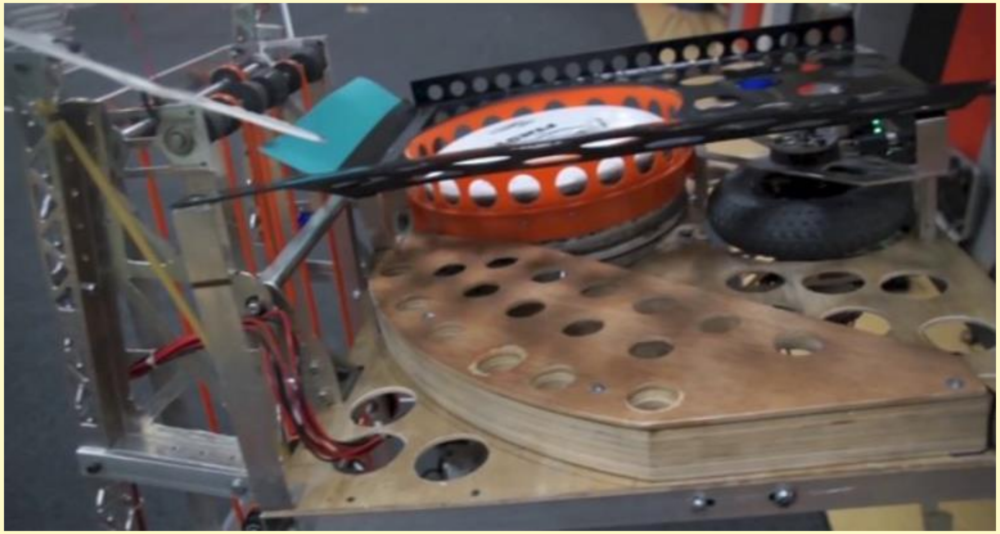
1771 in 2009

Circular Conveyer. One cylindrical roller inside. Rolling surface around outside

Frisbee Fling:

- Wheel rotates disc against a flat or curved surface.
- High speed ~5000 rpm
- Long surface & wheel contact time needed to get disc up to speed.
  - 2 wheel stages for linear shooters
  - 1 wheel for curved shooters

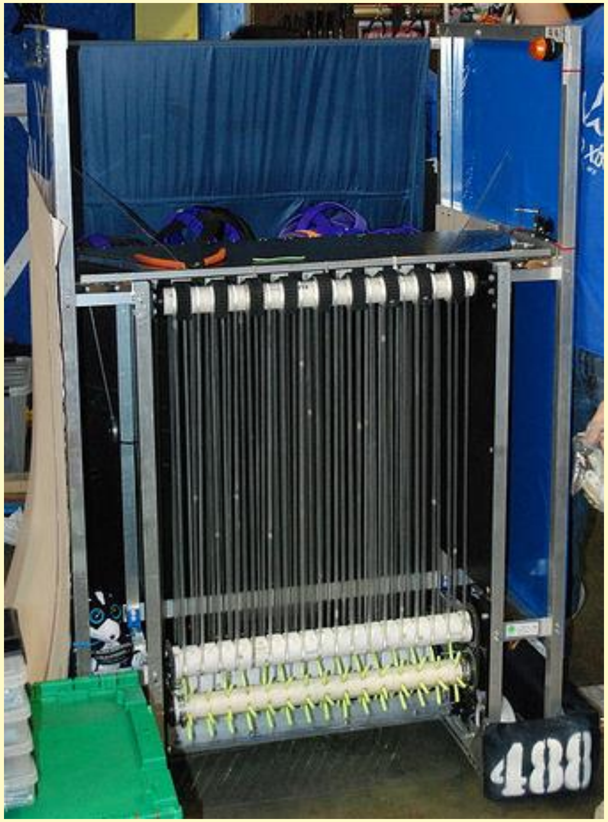




Buckets and Tables

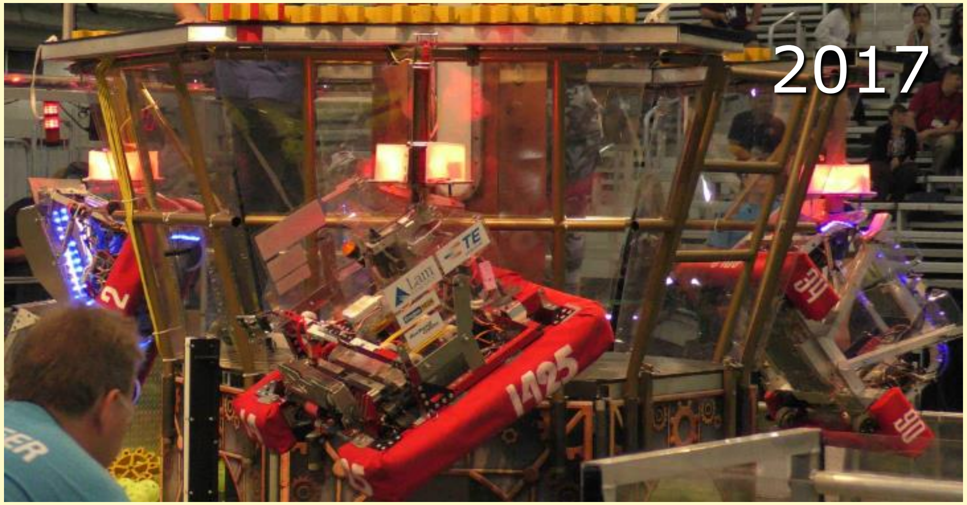
- Use for dumping many objects
- Integrate with your accumulator and conveyer
- Keep it light. Heavy buckets move slow
- Many ways to actuate.
  - Pneumatic, spring, gear, winch…

488 in 2009



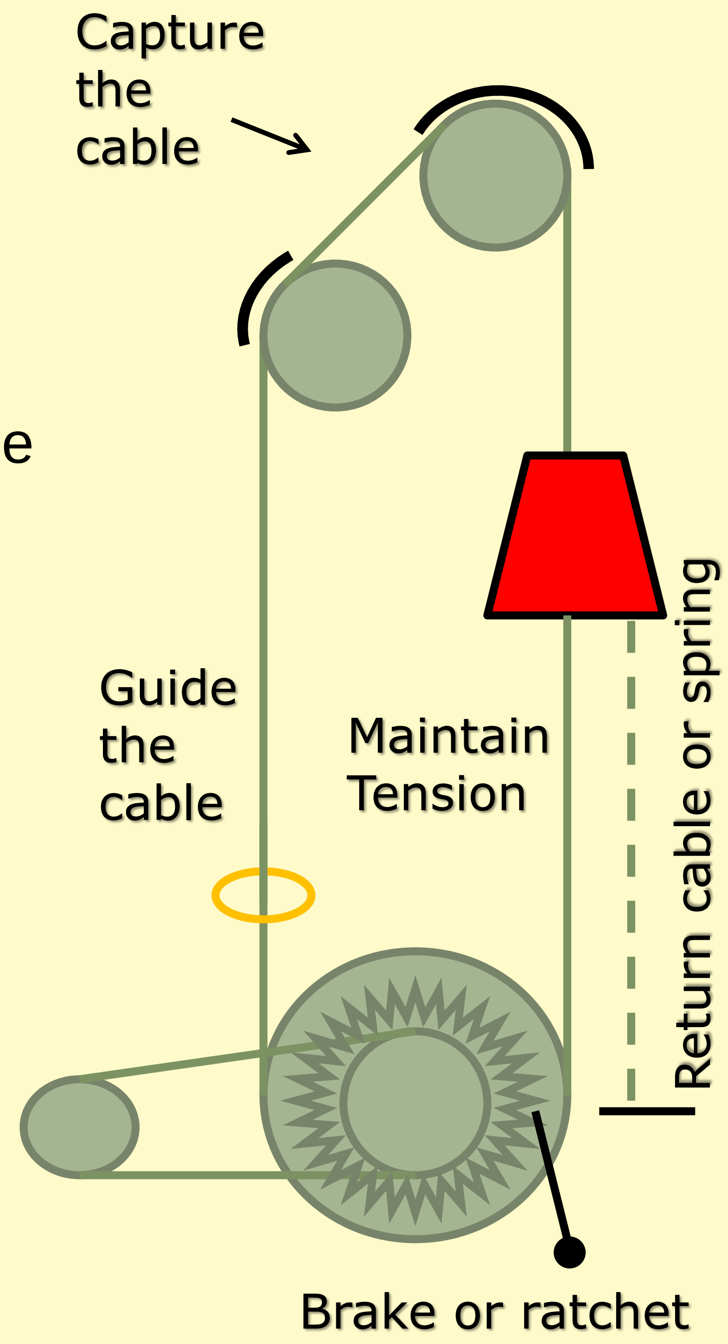
Winches

- Many uses
  - Climbing Robots: 2000, 2004, 2010, 2013 2016, 2017
  - Lifting Robots: 2007
  - Loading Kickers 2010, 2014
  - Lifting Totes: 2015
- High torque application
- Can fit into limited space
- Good for pulling or lifting



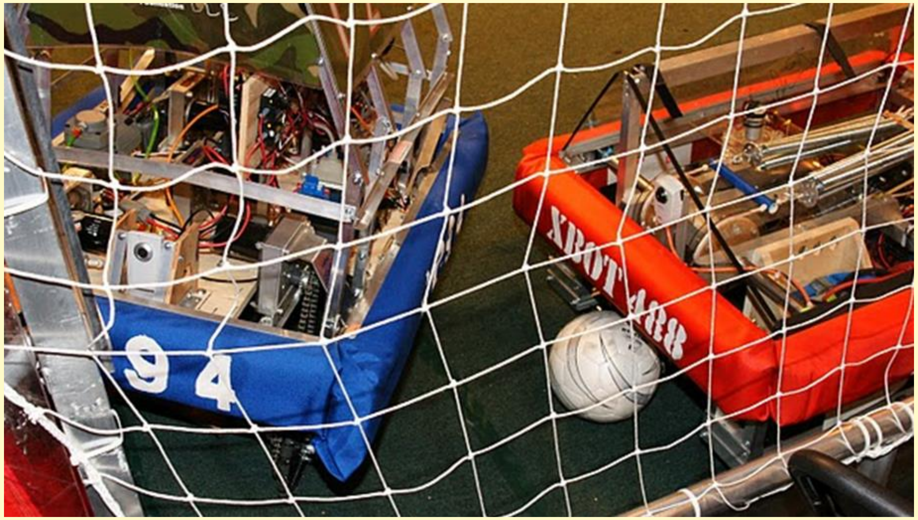
Winch Design

- Secure the cable routing
- Smooth winding & unwinding
- Leave room on drum for wound up cable
- Guide the cable
- Must have tension on cable to unwind
    - Can use cable in both directions
    - Spring or bungee return
    - Gravity return not recommended except after match ends
- Calculate the torque and speed
- Ratchet or brake to hold a position.



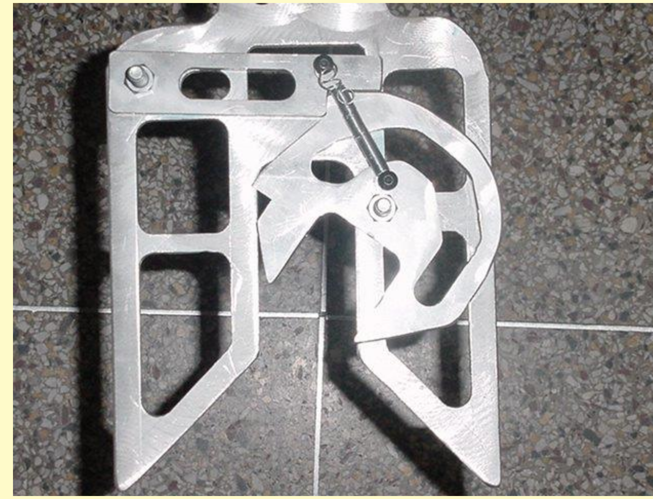
Kickers and Catapults

- Sudden release of stored energy:
  - Springs, Bungee, Pneumatic
- Design & test a good latch mechanism
  - Secure lock for safety
  - Fast release
- Also good for once in a game actions.
  - 2011 minibot release

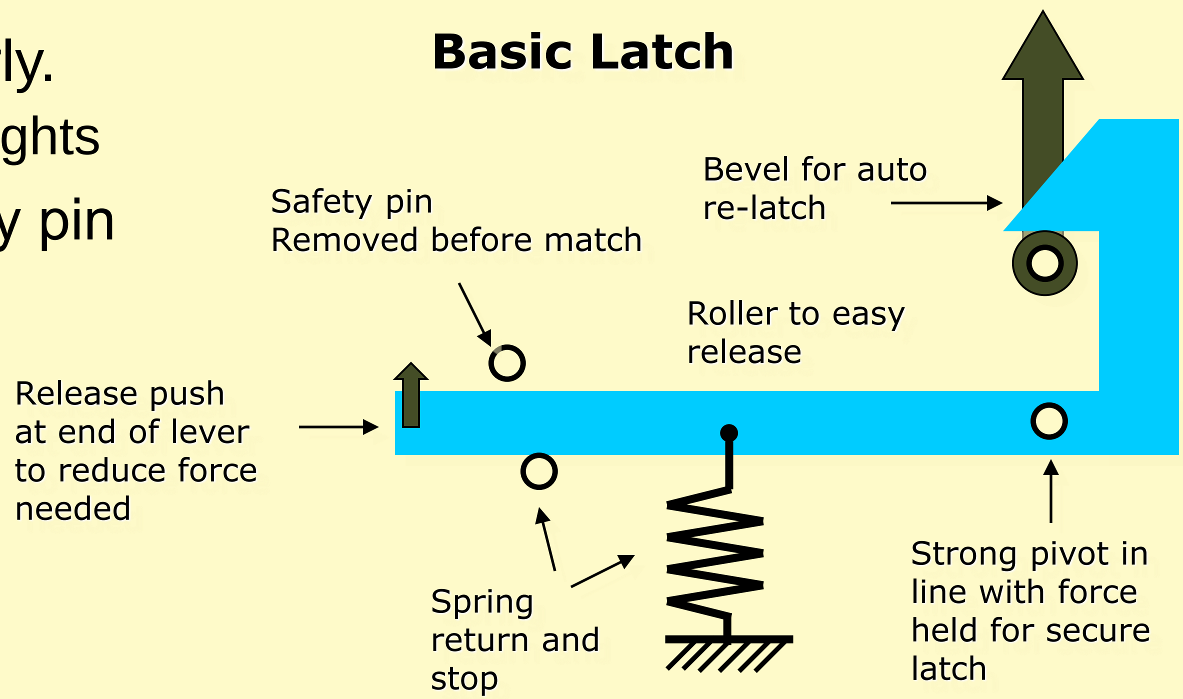


Latches

- Hook & hold to grab goals, bars, etc.
- Hold stored power until needed
  - Spring or bungee
- Several ways:
  - Hooks
  - Locking wheels
  - Pins
- Start latch design early.
  - Tend to be afterthoughts
- Don’t forget the safety pin

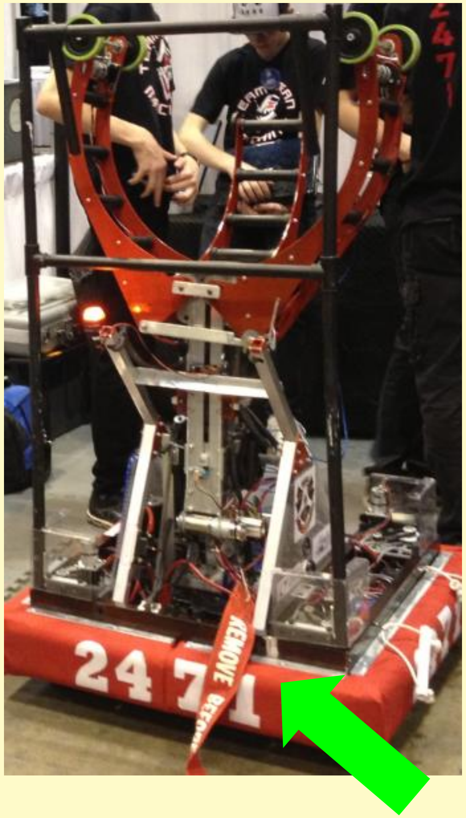


Self latching wheel lock



Design in Safety

- Any manipulator strong enough to play the game is strong enough to hurt someone.
- Design in locking pins, safety signs and safe stop points



Summary

- Know your design objectives and game strategy
- Stay within your capabilities
- Look around. See what works
- Design it before you build it
  - Calculate the forces and speeds
  - Understand the dimensions using CAD or models
- Keep it simple and make it well
  - Poor craftsmanship can ruin the best design
- Test. Test. Test. Under many conditions
  - Refine the design based on results
- Have fun doing it.

Appendix

Acknowledgements

- Many thanks to teams and companies who made materials for this presentation freely available on web sites to help FIRST students.
- Andy Baker’s original presentation and inspiration for this seminar is available on line.
- There are many examples and resources available.
  - Be sure to use them when planning your robot designs.

    http://www.societyofrobots.com/mechanics_gears.shtml

Motor Power:

- <u>Assuming 100% power transfer efficiency:</u>
- All motors can lift the same amount they just do it at different rates.
- No power transfer mechanisms are 100% efficient
  - Inefficiencies due to friction, binding, etc.
    - Spur gears ~ 90%
    - Chain sprockets ~ 80%
    - Worm gears ~ 70%
    - Planetary gears ~80%

It adds up!

2 spur gears + sprocket =

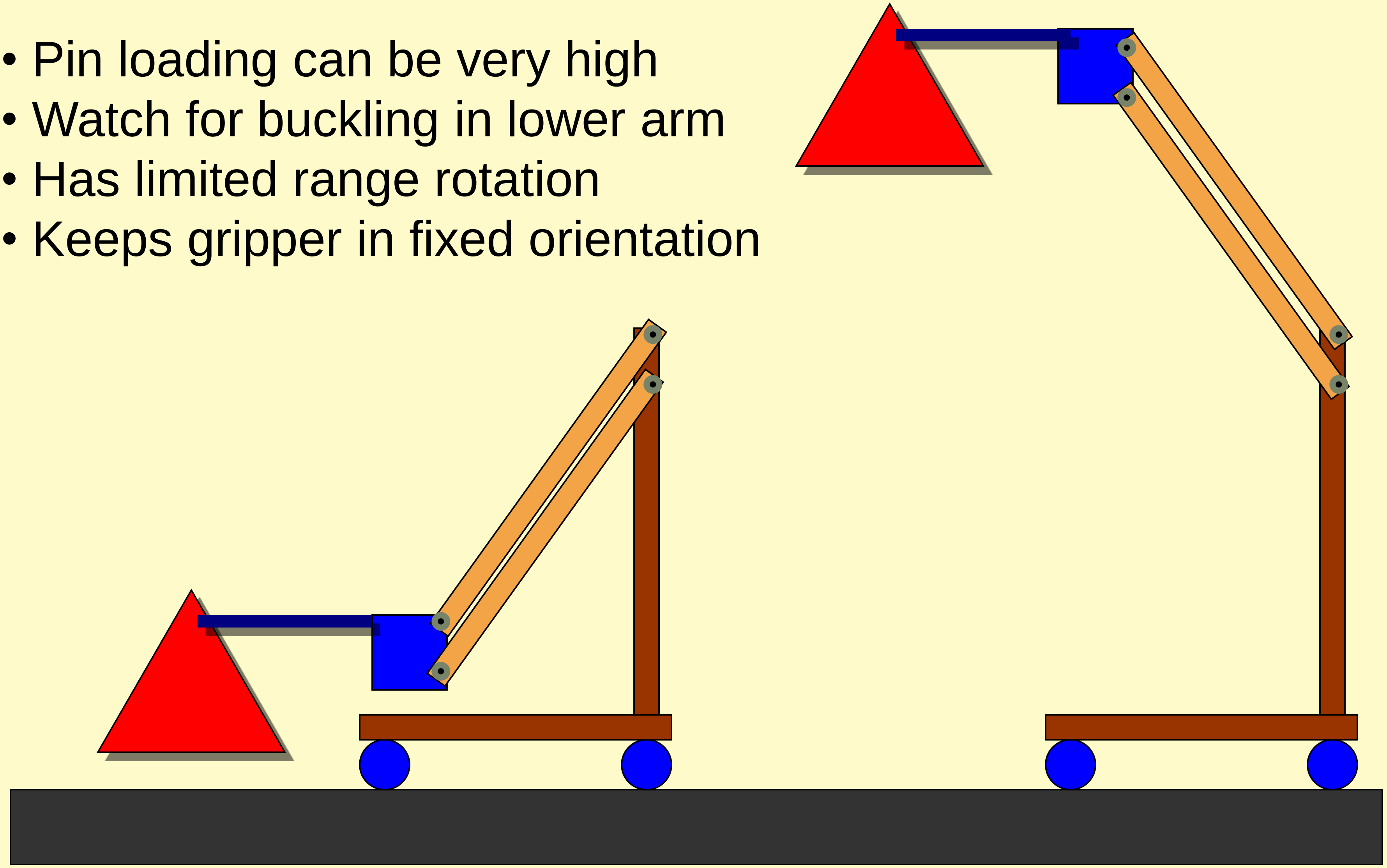
.9 x.9 x.8 = .65

Losing 35% of power to the drive train

  - Calculate the known inefficiencies and then design in a safety factor (2x to 4x)
- Stall current can trip the breakers

Parallel Arms

- Pin loading can be very high
- Watch for buckling in lower arm
- Has limited range rotation
- Keeps gripper in fixed orientation



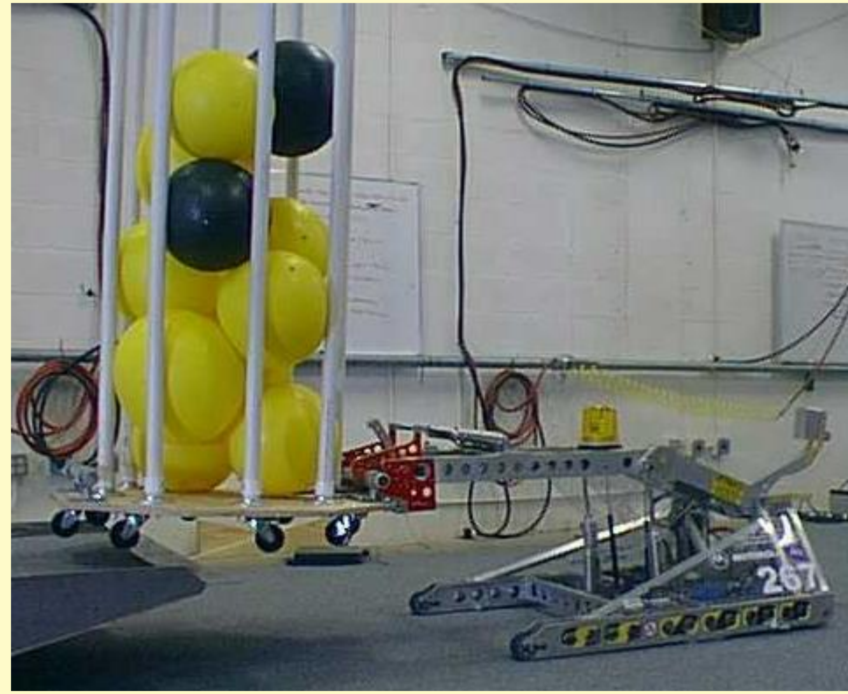
Scissor Lifts

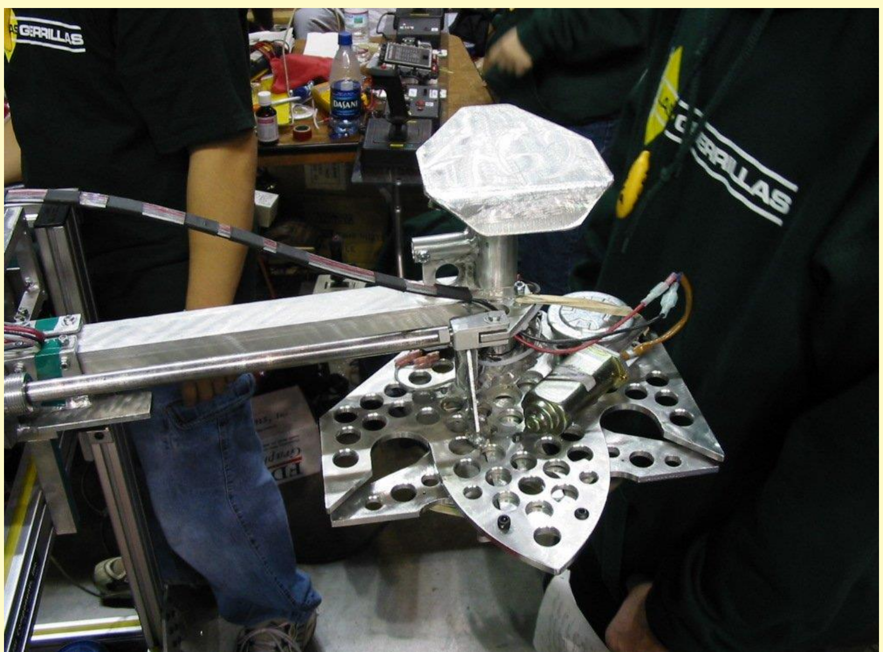
- Advantages
  - Minimum retracted height - can go under field barriers
- Disadvantages
  - Tends to be heavy when made stable enough
  - Doesn't deal well with side loads
  - Must be built very precisely
  - Stability decreases as height increases
  - Stress loads very high at beginning of travel

- **Not recommend without prior experience**

Latch Examples

- Pneumatic latch, solidly grabs pipe
- Force and friction only
- No “smart mechanism”

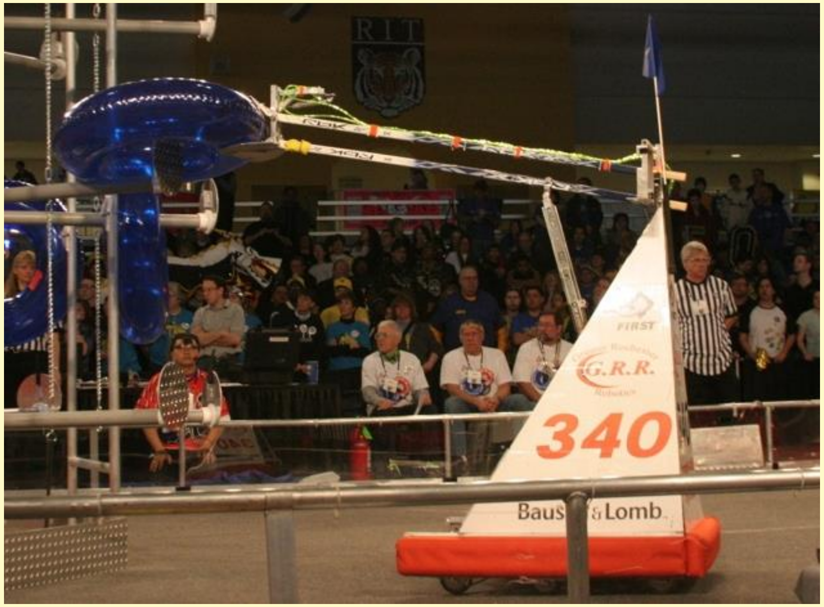


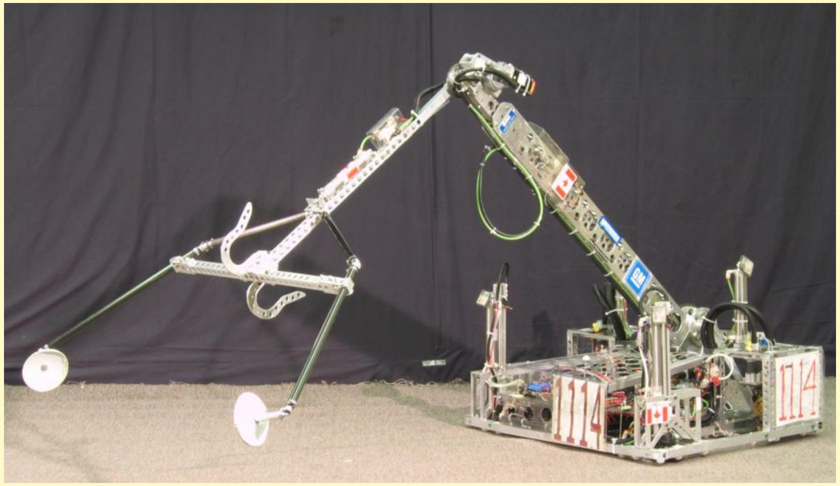


- Spring-loaded latch
- Motorized release
- Smart Mechanism

469 in 2003

Parallel arm





Jointed Arm

Fixed Arm

Brakes: Slowing and locking

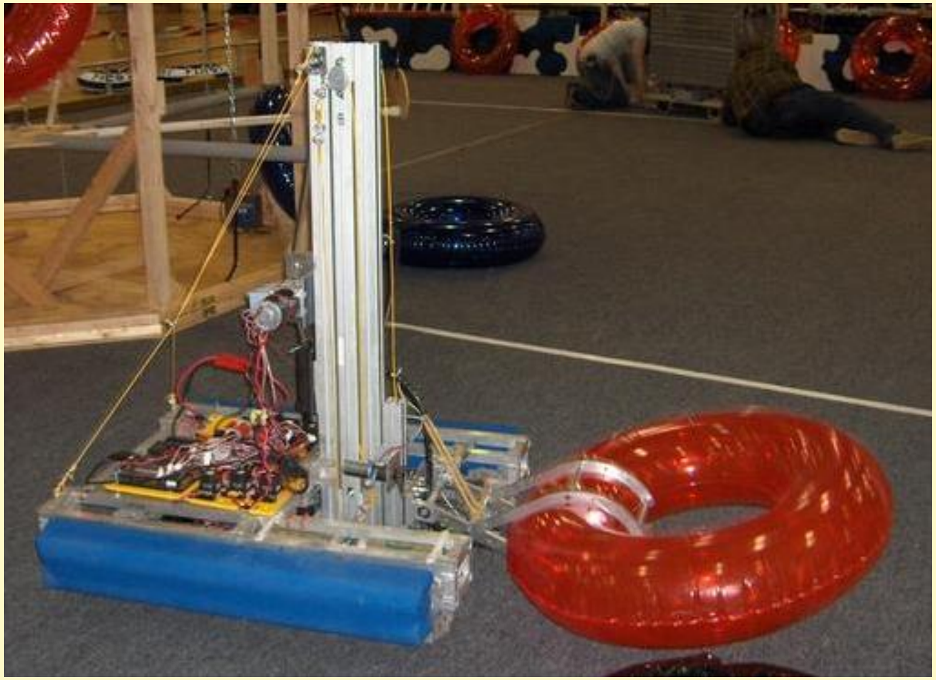
- Ratchet - Complete lock in one direction in discrete increments
- Clutch Bearing - Completely lock in one direction any spot
- Brake pads - Squeezes on a rotating device to stop motion - can lock in both directions. Simple device
  - Disc brakes - Like those on your mountain bike
  - Gear brakes - Apply to lowest torque gear in gearbox
  - Belt Brake- Strap around a drum or pulley
- Dynamic Breaking by motors lets go when power is lost.
  - Use for control, but not for safety or end game
  - Gearbox that cannot be back-driven is usually an inefficient one.

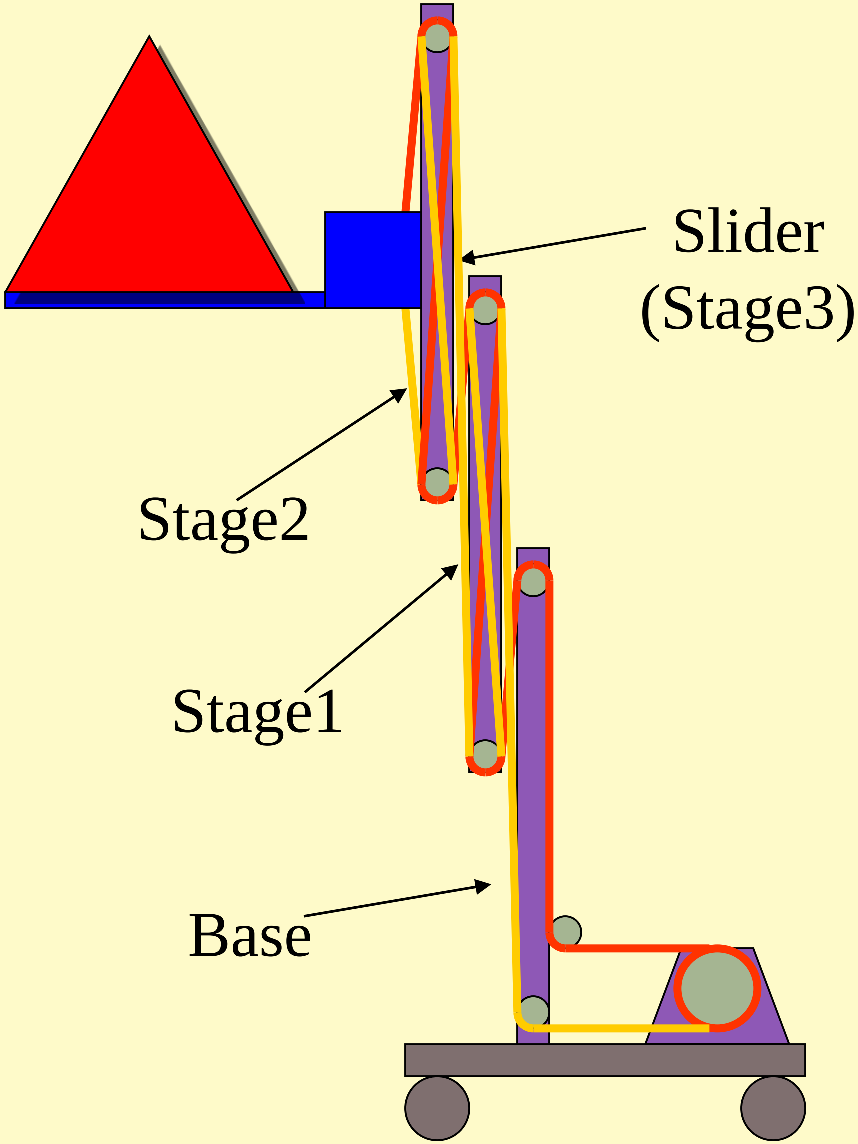
Latch Design

- Start design early. Latches tend to be afterthoughts but are often a critical part of the operation
- Don’t depend on driver to latch, use a smart mechanism
  - Spring loaded (preferred)
  - Sensor met and automatic command given
  - Use operated mechanism to let go, not to latch
- Have a secure latch
  - Don’t want release when robots crash
- Be able to let go quickly
  - Pneumatic lever
  - Motorized winch, pulling a string
  - Cam on a gear motor
  - Servo (light release force only)
- Don’t forget a safety pin or latch for when you are working on the robot

Continuous Internal

- Pull-down cable routed on reverse route of pull-up cable
- Most complex cable routing
- All stages have active return
- Cleaner and protected cables
- Drum differential not needed.





Combination Example:

2011

- Continuous direct drive chain runs stage 1 up and down
  - Drum differential not needed
- Telescoping arm with wrist on slider stage to add reach