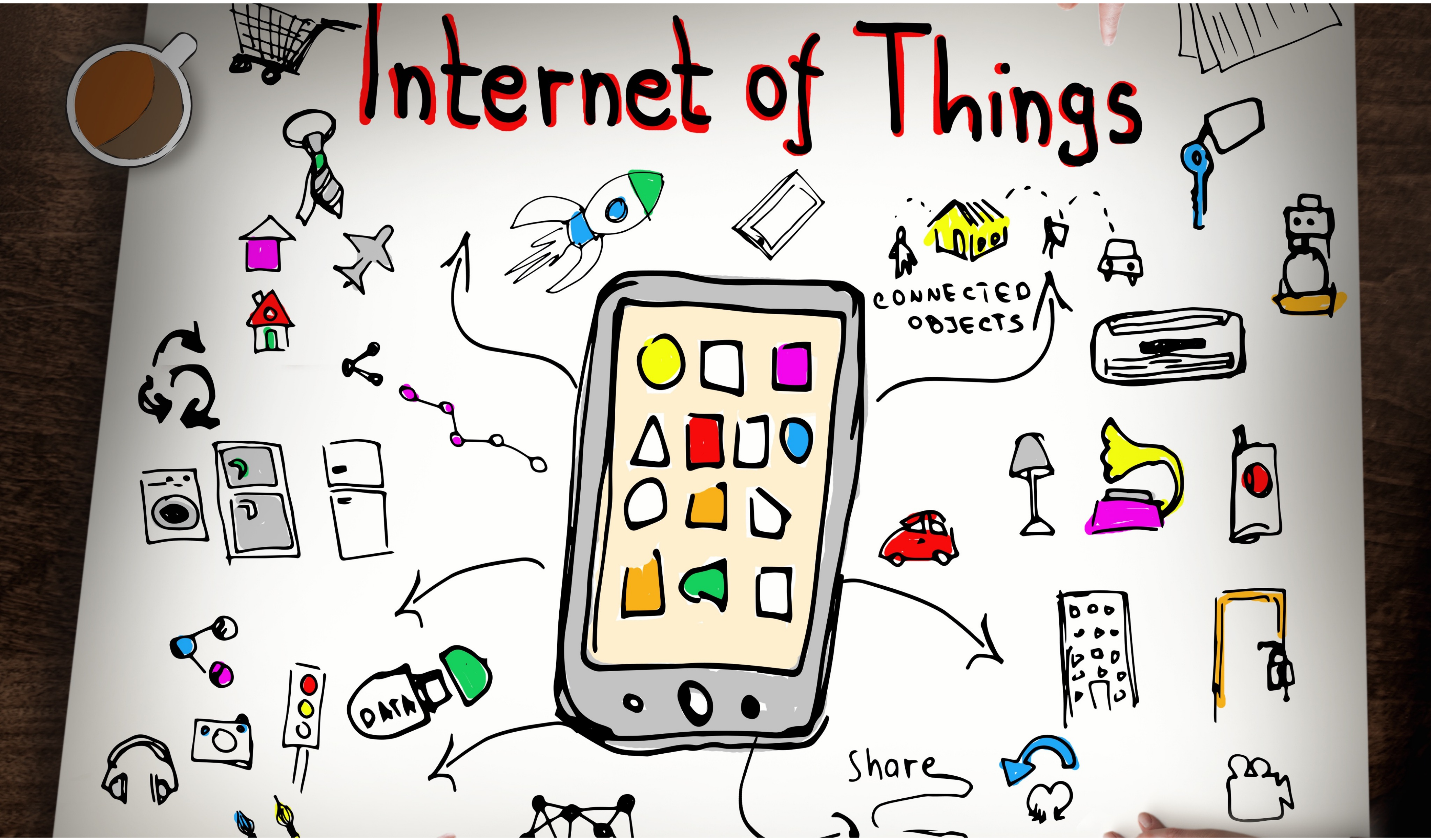

Officiating Technologies in Sports

18-738 Sports Technology

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Overview

- Evolution of officiating technologies
- Electronic line-judge
- Hawk-Eye
- Hot Spot
- Snickometer
- Adidas’ Cairos goal-line
- Research at Carnegie Mellon

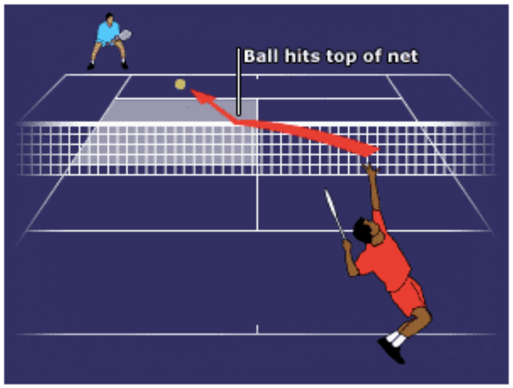
Technology for Officiating

Electronic Line-Judge Experimentation

- Technology introduced in early 1970s to improve officiating in tennis
- Used to detect where a ball has landed on the tennis court
- Goals
    - Detect whether the ball was inside/outside the boundary lines
- Original version (1974) was the Grant-Nicks pressure-sensor system
    - Grant was a keen tennis player and Nicks was an electronic engineer
- Thin mylar conductive plastic pressure sensors beneath court surface
- Could differentiate between a player's foot vs. the ball

  Ball = point contact. Player = more coverage.
    - Signature of a ball's millisecond bounce vs. human footfall's duration
    - Normal player movements couldn't accidentally trigger the system
- "In" and "Out" sensors on the boundary lines of the court

Tennis Rules



A ball which clips the net and bounces inside the service box is known as a 'let'.

If this happens the player is allowed to serve again.

However, if the ball hits the net and lands outside the service box, it is a fault.

A 'let' can also be called during any point in the match if it seems fair for a point to be played again.

For example, if there is a dispute over a line call.

If the server throws the ball in the air but does not attempt a shot, it is a 'let'.

If the server throws the ball in the air, attempts a shot but misses, it is a fault.

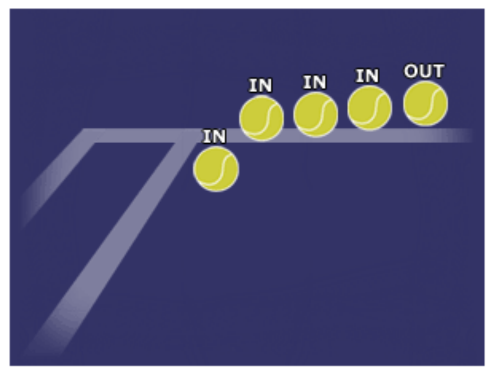
Ball clipping the net -- if the ball clips the net.
Net clip detection is not done by directional mic.
It is done by net cord connect with electric sensor.

The server must stand behind the baseline, between the centre mark and the sideline.

A 'foot fault' is called if any of the following happens before the ball is struck:

- The feet touch the ground inside the baseline
- The feet touch the wrong side of the centre mark OR
- The feet touch the wrong side of the imaginary extension of the sideline.

A foot fault is the same as a fault on a serve so the player is given the chance of a second serve.



The player must be inside the area. Where is the player?

Directional microphone synchronized to detect who hits the ball with racket.

The server has two attempts to get the ball in.

If the ball lands outside the service box or does not clear the net or the net post, it is known as a 'fault'.

If any part of the ball touches the line, the ball is in (as shown above).

After one fault the server may try again. If both tries result in faults, a 'double fault' is called and the opponent wins the point.

Electronic Line-Judge Experimentation

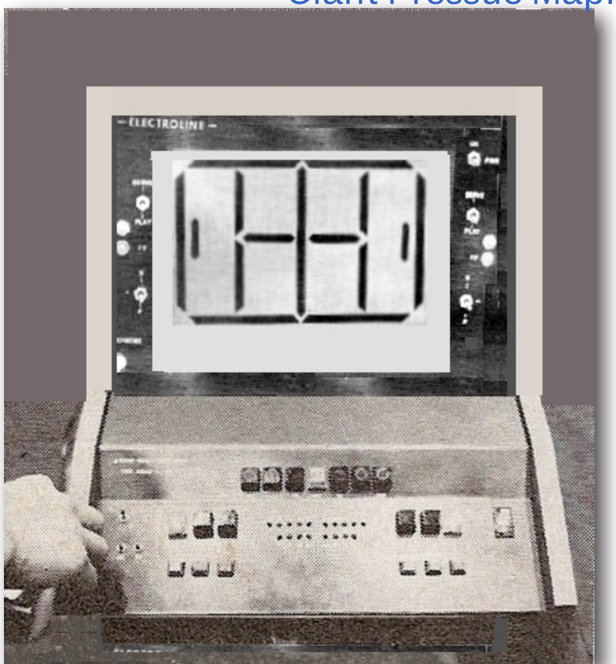
We need to know the distance from the lines, where the player is serving -- directional microphone.
We can hear which of the two is serving. Sound of ball hitting the racket.

- Added objectives
  - Make decisions on foot-faults and service net-cord legal serves
- Required additional sensors to be incorporated
  - Directional microphones to detect a player’s racquet striking the ball
  - Synchronized with player’s foot triggering the “In” boundary-line sensor
  - Net-cord with piezoelectric sensor (a guitar pick) to detect touching of net
- Interesting combination of number of sensors working together
  - Service-line sensor + net-cord sensor + foot-fault sensor + microphone
  - Turned “on” together when a player served the ball
  - Turned “off” as opponent returned the ball

Electronic Line-Judge Experimentation

- Inaugural Grant-Hicks prototypes demonstrated in 1974
  - Service lines: Men’s World Championships, Dallas, 1974
  - + Net calls, all lines: Ladies’ Virginia Slims Championships, L.A., 1975
- Additional system demonstrated by David Lyle in Edinburgh, 1977
- **Neither Grant-Hicks’ or Lyle’s systems made it into commercial products**

Giant Pressue Map. It was a demo but never made it commercial.



A visual diagram. It is self-operating, fascinating operating system.

Cyclops: Commercial Line-Judge System

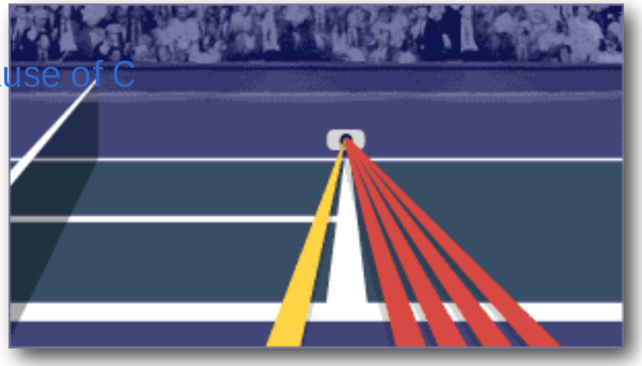
First commerical line system.

- Invented by Bill Carlton and Margaret Parnis England
    - Focus only on service-line calls, but commercially successful
    - Introduced at Wimbledon Championships (1980), U.S. Open (1981)
- Different from the early experimental prototypes
    - Service-line judge turns the system “on” before each serve
    - Array of 5-6 horizontal infra-red beams, 1cm above ground
    - Loud beep noise whenever ball breaks beams beyond service line

      Loud beep noise when the ball breaks beyond the service.
    - False alarms due to insects flying in front of beams at times

      Infrared-Red - Line to Line technology.
- Moment of notoriety
    - Ilie Nastase, Wimbledon 1980

      He was called against because of C Cyclops.
    - Went down on his knees to Cyclops to argue call



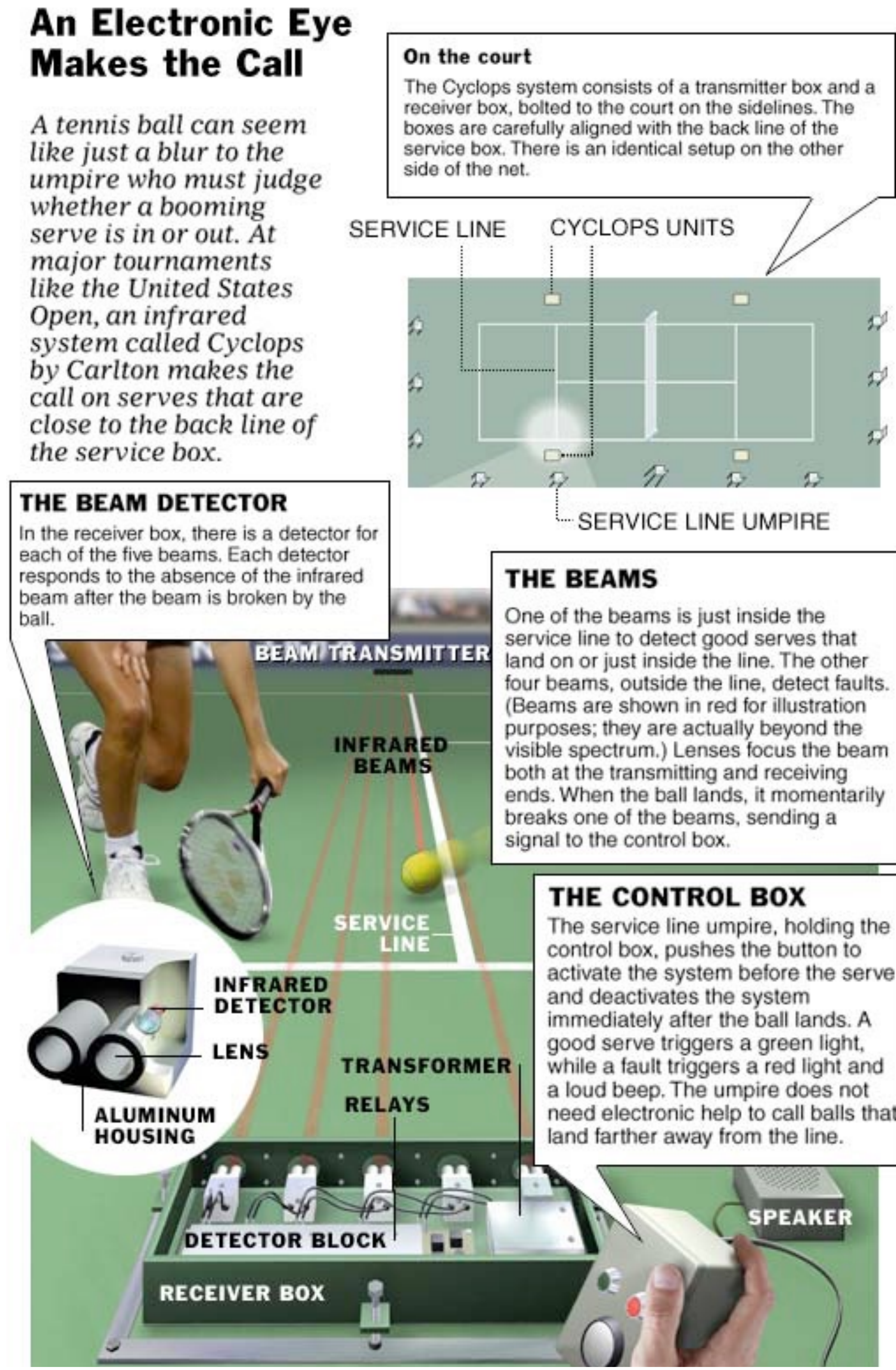
Cyclops

- Control box with service-line umpire
- Audible beep when serve was long
- Phantom beeps at times

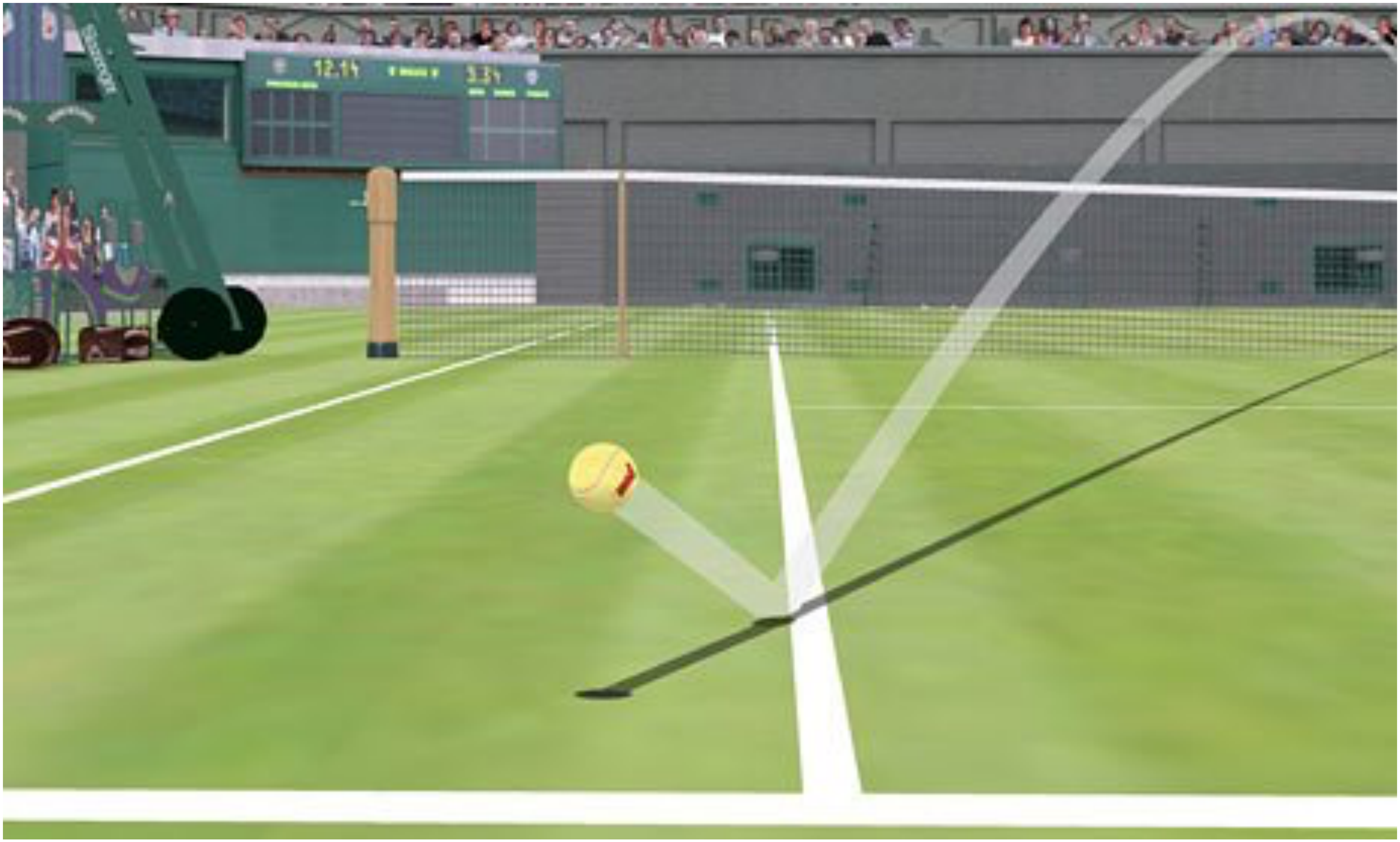
There are four of them, transmitter and receiver, line of sight. Indentical setup. Commericially Viable. Still issues with insects.

“I don’t want to sound paranoid, but that machine knows who I am.”

John McEnroe to an umpire



Hawk-Eye



Hawk-Eye

Traks real-time 3D dimension fly path of the ball.
It started to make for TV viewing better. It was not invented for judging at first.
Traditionally the Tennis Umpire will watch the ball and make judges subjectively.

- Invented by Dr. Paul Hawkins
  - System to track the real-time trajectory of a moving ball
  - Objective to display its most likely path as a moving image
  - Introduced for television viewing for cricket in 2001
- More of a computer-vision-based system
  - System of 6-7 high-performance cameras placed high above the court
  - Cameras track the players and the ball
  - Video data from the cameras is processed by computers

    Real-time stitched images to provide 3D view.
  - Video combined to create a 3D representation of ball trajectory

    Taking muliple images simultianeously.
  - Processing takes into account player skid and ball compression

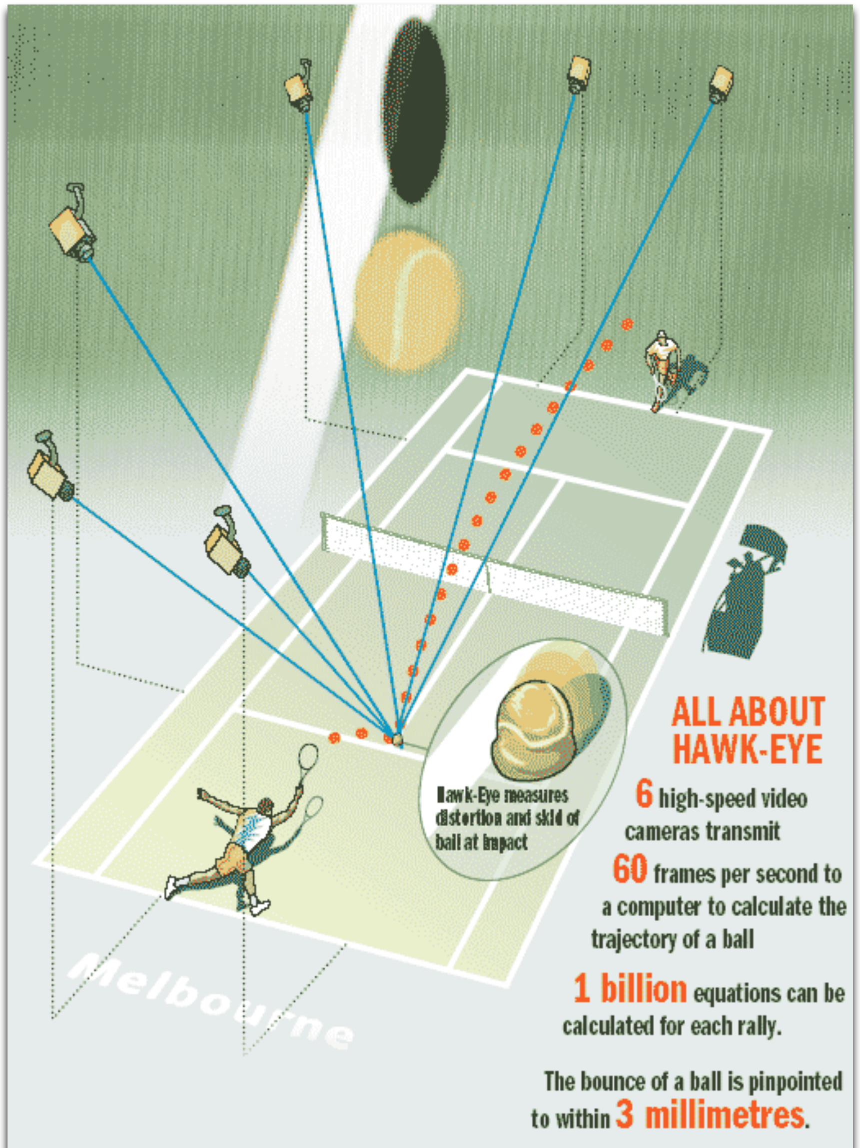
    The ball bounces on the ground, the moment where it almost flattens and bounce back up. It takes that into account.
  - Accurate to within 5 mm

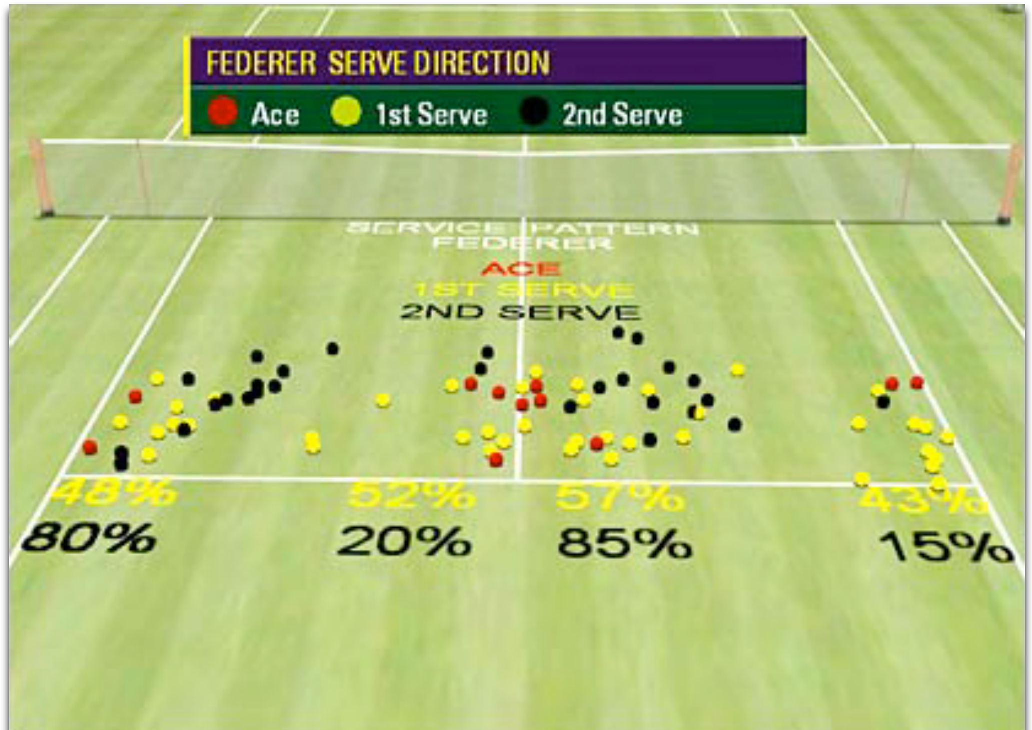
Hawk-Eye: Commercial Use

- Used in many sports
  - Since 2006 in tennis
  - Since 2009 in cricket (Umpire Decision Review System)
  - In 2013-2014 for the Premier League (goal-line technology)
  - In 2007 for snooker
  - In 2014 for the Australian Football League
  - In 2011 for the Gaelic Games
- The French Open is the only Grand Slam not to use Hawk-Eye

French Open there's a clay court -- the clay sticks to everything, to the shoes, kits everything. The ball start to look different and computer vision is hard to track that.

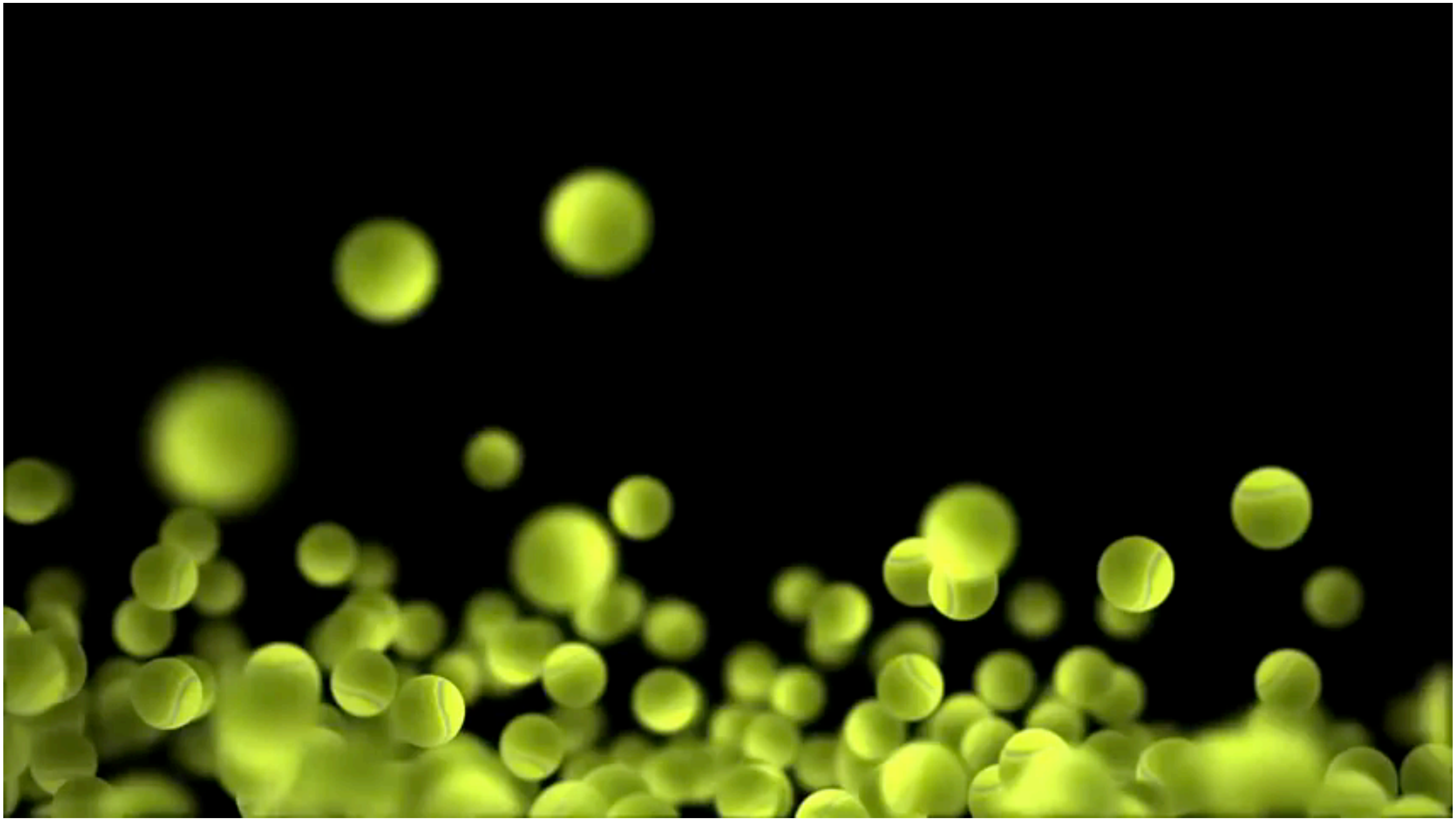
Hawk-Eye: Statistics





Inside Hawk-Eye

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



Hawk-Eye: Issues

Chanellenges:

1. How does it track trajectory
2. How does it work under different lighting conditions
3. Latency.
4. Wind / Ball Compression...

- Computer vision is not without its challenges
- Indian Wells 2009
  - Quarterfinal between Ivan Ljubicic and Andy Murray
  - Hawk-Eye incorrectly called a Murray shot to be “in”
  - Turned out later that it had accidentally taken image of a second bounce
- Australia 2009
  - Match between Roger Federer and Tomas Berdych
  - Berdych challenged an “out” call
  - But Hawk-Eye did not work due to large shadow on the court

Not everyone is a fan

Berdych joins Federer in anti-Hawk-Eye club

January 27, 2009 2:40:54 AM EST by IANS +1 0 Tweet 0 Recommend Share 0

Melbourne, Jan 27 (DPA) Tomas Berdych has joined Roger Federer in slamming the Hawk-Eye electronic line-calling system after its failure struck him at a key moment in his losing fourth-round match to the Swiss star at the Australian Open.It's no secret that traditionalist Federer has never been a fan of the system - and his poor record on challenges proves that point.

But the system really caught Berdych at a bad time when it failed to function on a challenge he made - likely because of a deep shadow over one side of the court in late afternoon.

So, instead of proving a call right or wrong, the electronic glitch meant that the call stood, with Berdych erupting as he led two sets to one with the tide starting to turn.

"If they bring some new system (in) and (it) doesn't work, why should it be on the courts?" said Berdych. "He (chair umpire) can tell you whatever he wants. Hawk-Eye should be working."

Federer agreed: "What do I think about it? It's horrible. Finally one guy (Berdych) understood.

"I don't think you win or lose a match because of them. If it's nine-all in the fifth set, you got to use it and there's a terrible call because the lines-person was sleeping and the umpire was drinking coffee, of course then it's good you have it.

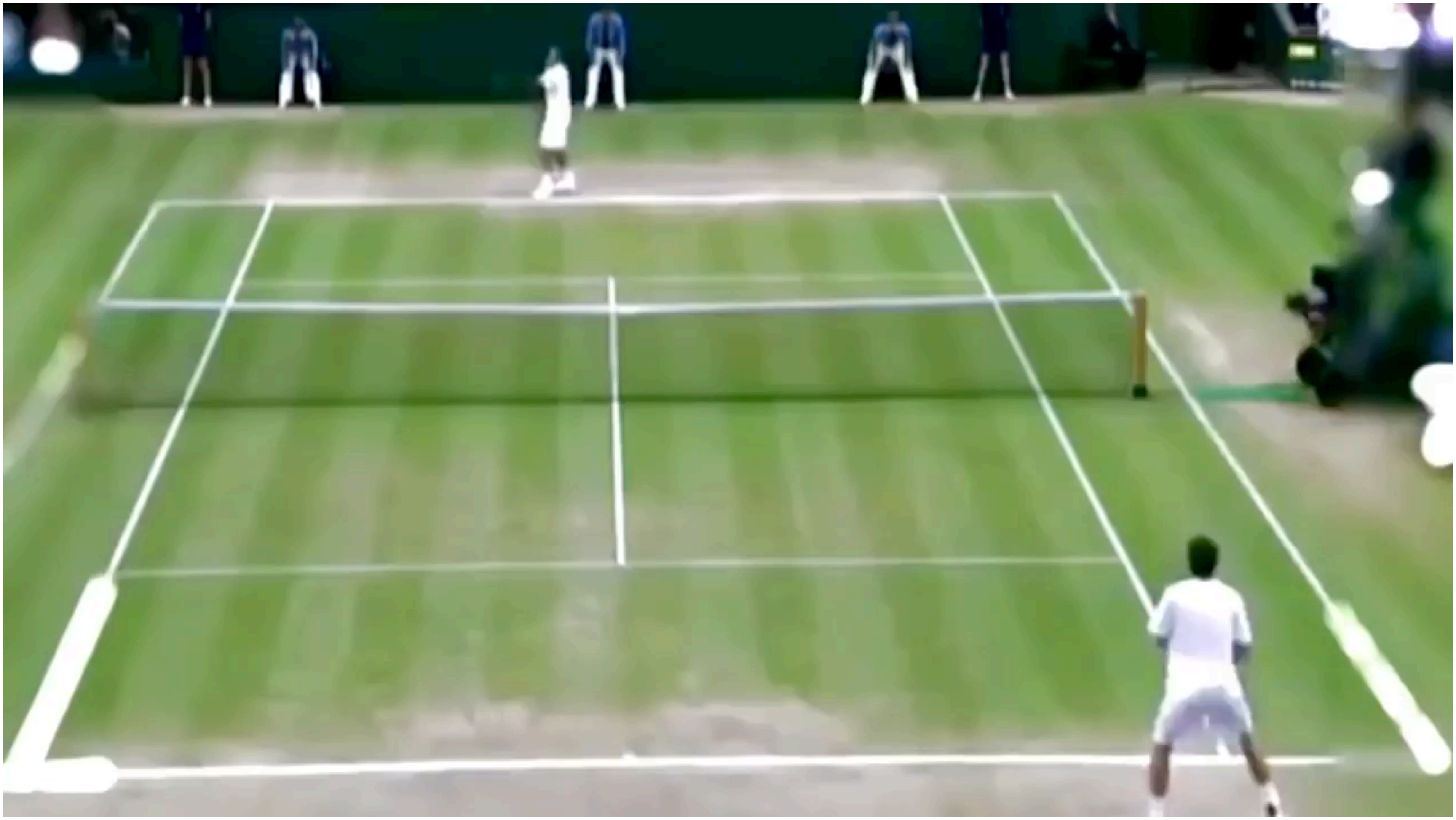
"With a system like this is in place, it shouldn't happen, right?"

Federer's record with the system is among the worst in the game with 19 challenges at the Open with just four correct so far.

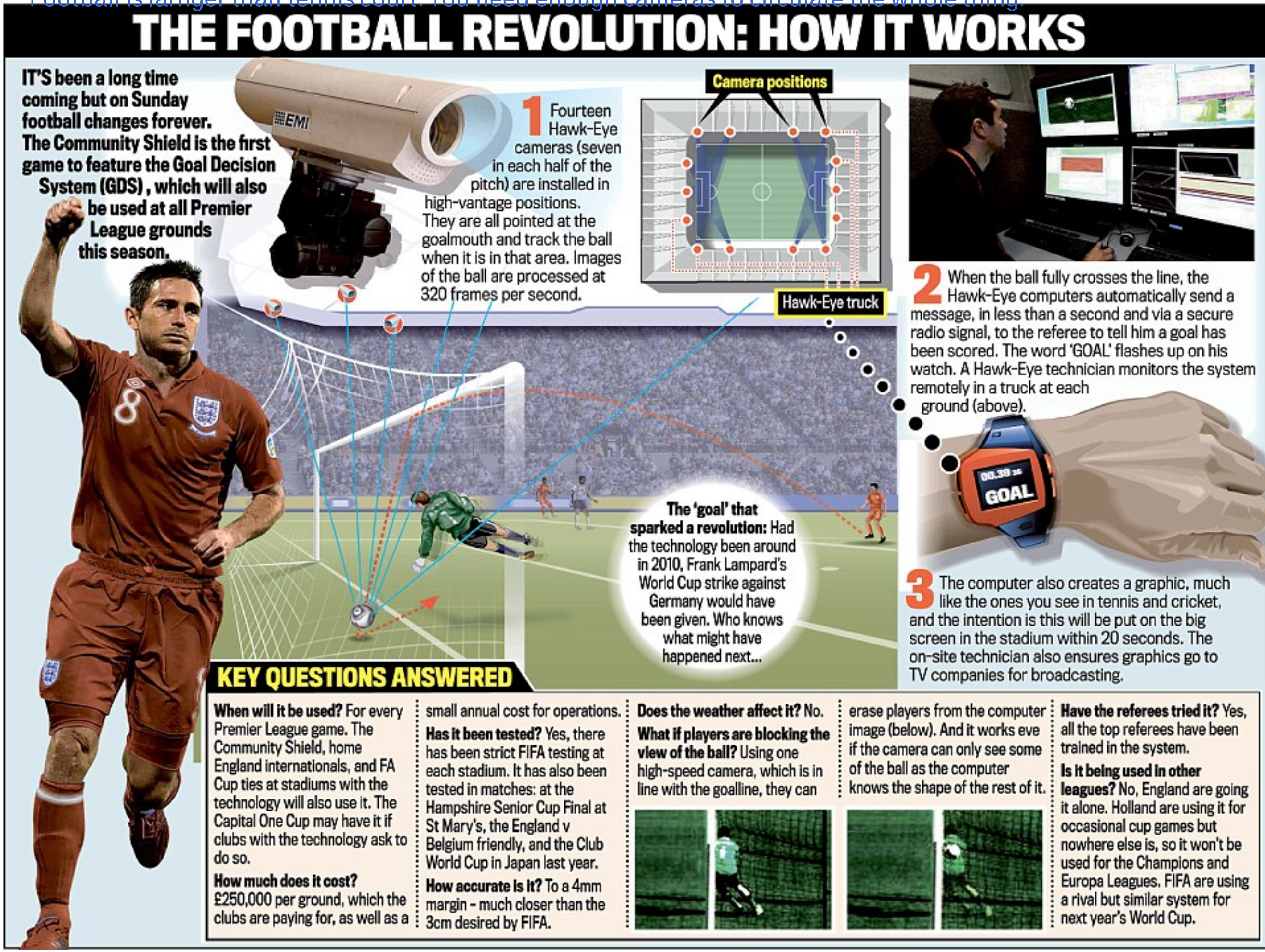
Yup, not everyone is a fan

Yup, not everyone is a fan

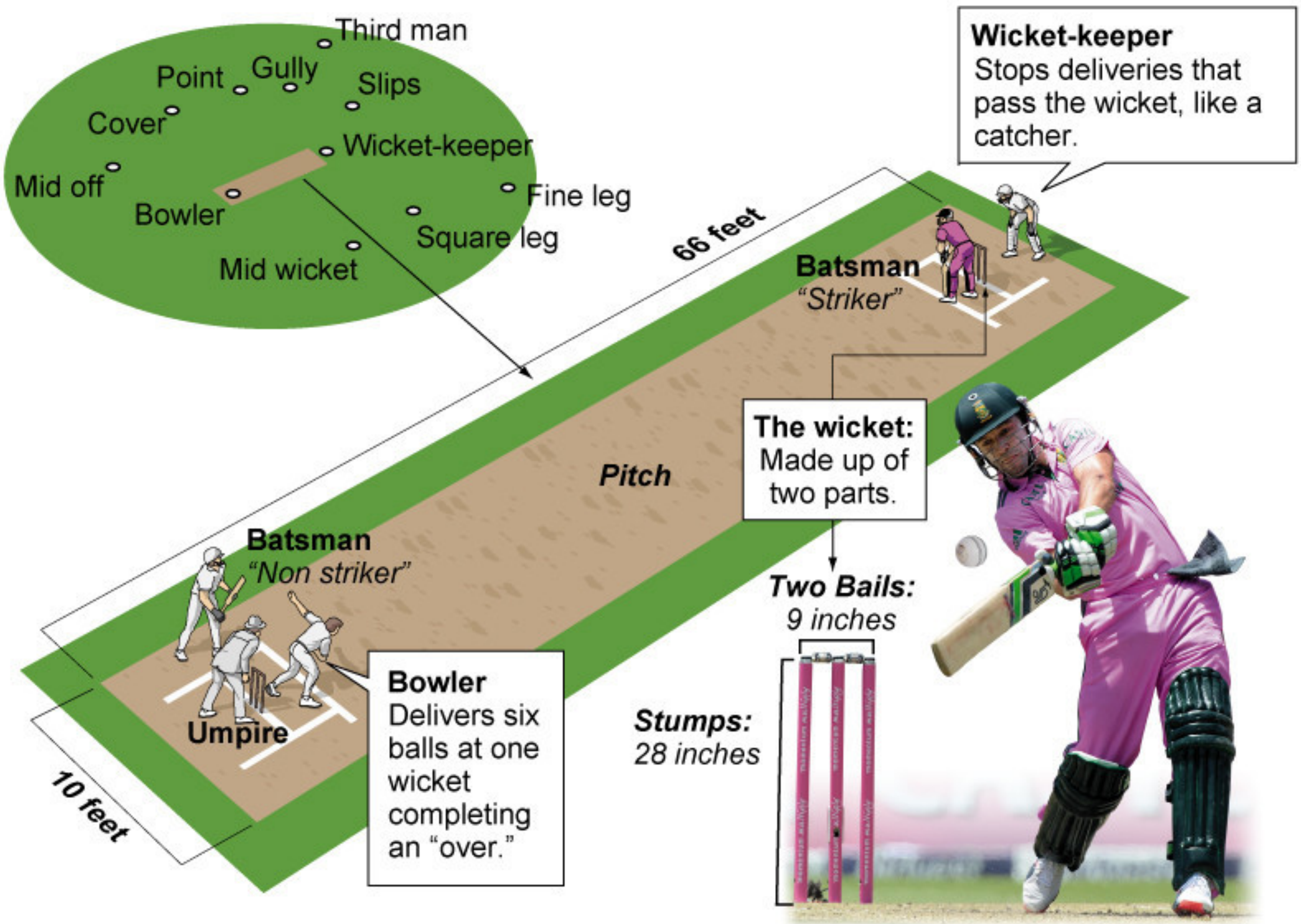
The fans can see the trajectory.
Both at home and in the stadium.



Football is larnger than tennis court. You need enough cameras to circulate the whole thing.



Cricket rules



Getty photo

A specific rule in cricket: LBW

Leg before wicket.

LBW tells why trajectory is important.

Ways of getting out: Leg before wicket

Three vertical line is the stump. They actually behind the person.

The leg before wicket (lbw) law is to cricket what the offside rule is to football - confusing.

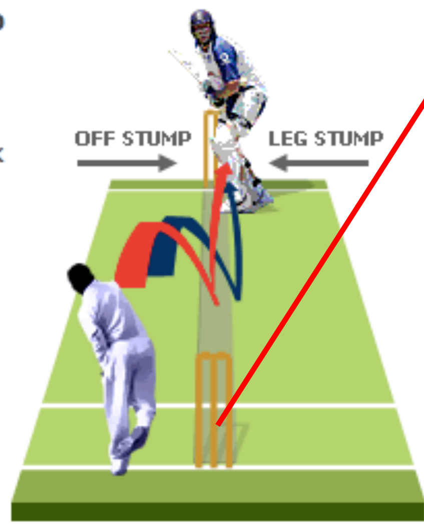
However, you do not need a PhD from Oxford or Cambridge University to work it out - just this simple guide.

The umpire will consider an lbw decision if he believes the ball would have hit the stumps had it not been obstructed by the batsman's pads.

But the umpire also has to take other factors into consideration.

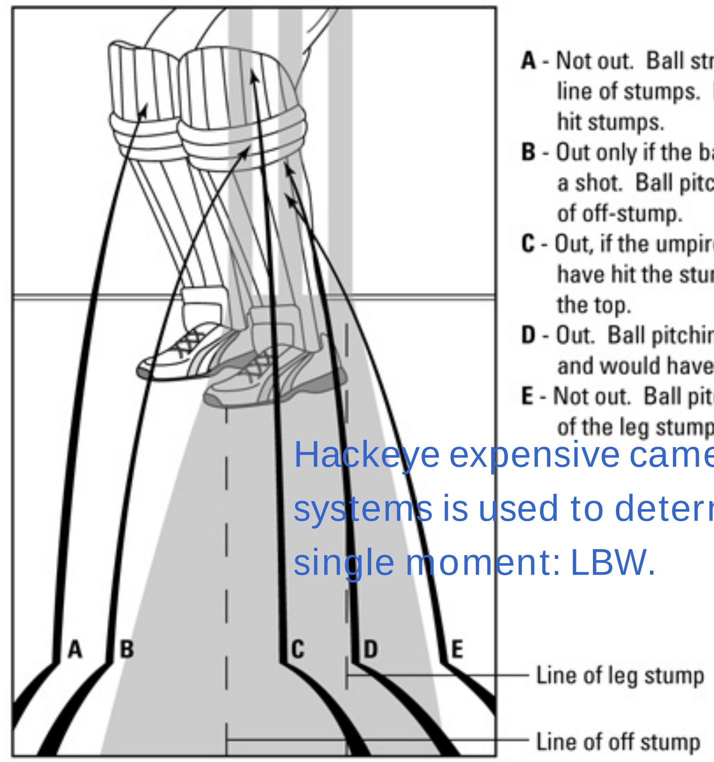
- Our full, illustrated guide to the lbw law

Leg before wicket



OUT: ball has pitched and struck pad in front of the stumps

NOT OUT: ball has pitched outside leg stump



A - Not out. Ball striking pad outside line of stumps. Ball would not have hit stumps.

B - Out only if the batsman did not play a shot. Ball pitched outside the line of off-stump.

C - Out, if the umpire feels the ball would have hit the stumps and not missed the top.

D - Out. Ball pitching on line of leg stump, and would have hit the stumps.

E - Not out. Ball pitched outside the line of the leg stump.

Hackeye expensive cameras and systems is used to determine this single moment: LBW.

THE BATSMAN IS NOT OUT...

If the ball pitches outside the line of leg stump, regardless of whether or not the ball would have gone on to hit the stumps.

If the ball hits the bat before striking the pad.

If the batsman is struck on the pad outside the line of off stump having made a genuine attempt to hit the ball.

If the bowler bowls a no-ball.

Snickometer

Cricket they want to know in the case of LBW case B, they want to know if the batma has hits the ball.
Snickometer ~~= a microphone.
Snick is the sound where the bat hits the ball.

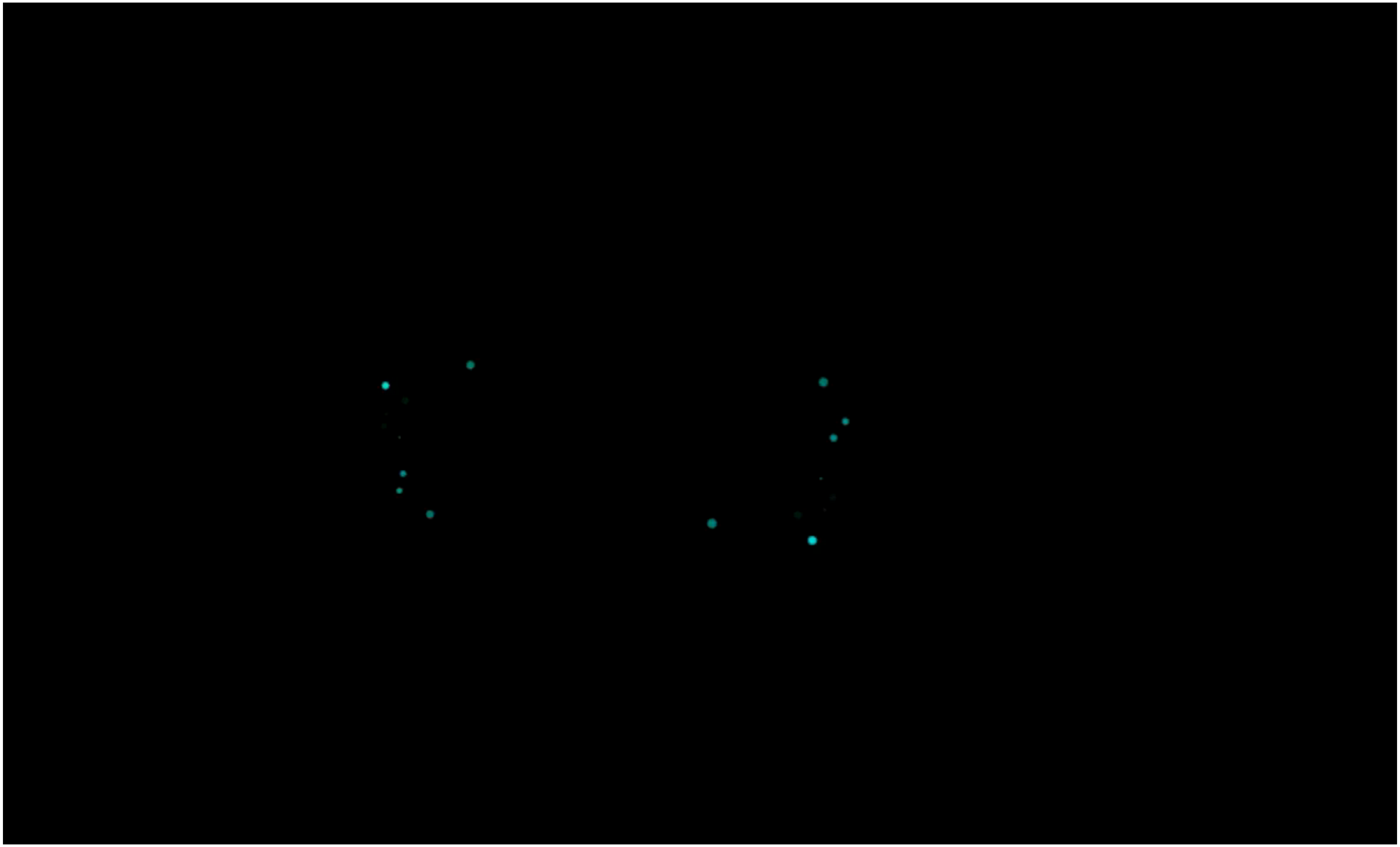
- Invented by Alan Plaskett in mid-1990s
  - Snick = fine noise (sound made by a ball striking a bat, for instance)
  - Used by Channel 4 in the U.K. in 1999
- Sound-based system to determine if the ball has struck the bat
  - Record of sound and movement (video)
  - Graphical analysis of the sound and video combined
  - Humans listen to, and view, the recorded sound-wave shape
  - Different sound signatures for ball striking bat, ball striking batsman, etc.
  - Friction elevates local temperature and can be detected on a thermal map
- Used extensively in cricket, until replaced by Hot Spot

Snickometer

Hot Spot

- Invented by Nicholas Bion
  - Originally developed in the military for tank and fighter-jet tracking
  - Used first in the 2006-7 Ashes Test Match at The Gabba, Australia
- Infra-red system to determine if the ball has struck the ball, batsman or pad
  - System of 2 IR cameras on opposite sides of the ground above play
  - Continuously recording the images
  - Relies on the fact that the point of contact generates friction
  - Friction elevates local temperature and can be detected on a thermal map
- Important for specific play calls in cricket
  - Where a determination is made for LBW or player being dismissed

Overview of Technologies Used in Cricket



Umpire Decision Review System (UDRS)

- Introduced by the International Cricket Council
  - Introduced at an India vs. Sri Lanka game in 2008
  - Used to determine whether a batsman should be dismissed
- Three components in UDRS
  - Hawk-Eye
  - Hot Spot
  - Real-time Snickometer
- Typically, a non-match umpire sits separately and reviews all plays
  - Using the combined information from all components of the UDRS

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Hawk-Eye: Cricket vs. Tennis

In **cricket**, the system automatically calculates the following information:

- The speed of the ball leaving the bowler’s hand.
- The swing of the ball from the bowler’s hand to its ‘pitch’, or bounce
- How much the ball has bounced
- How much the ball spun sideways off the wicket
- A prediction of where the ball would have passed the stumps

In **tennis**:

- Hawk-Eye cameras are placed high above the court to track the ‘trajectory’ (or path) of the ball.
- It can point out the bounce of the ball up to the precision of 3.6mm.
- The cameras record the movement of ball at the rate of 100 frames per second.
- The Hawk-Eye System can incorporate more video replay cameras for analysis from different angles, which can be controlled remotely.

Hawk-Eye in Cricket

Soccer Goal-Line Technology

- July 2011, FIFA decided to test 9 different goal-line technologies
- FIFA President Sepp Blattner reversed his opposition to goal-line technology
  - After 2010 World Cup, 2nd-round, England vs. Germany
  - When Frank Lampard had a clear goal disallowed
- FIFA requirements
  - Recognition of free-shots on goal with 100% accuracy
  - Match referee must know within 1 second if a goal has been scored
  - Message must be relayed to referee’s watch
  - Message must be in the form of a vibration and a visual signal
  - Message must be received wherever the referee is in the field of play
  - System must work in daylight and floodlit conditions

FIFA and Soccer Goal-Line Technology

- FIFA has granted goal-line technology license to some of the technologies

- Adidas Cairos GLT
- Hawk-Eye
- GoalRef

Adidas’ Cairos Goal-Line Technology (GLT)

- Smart ball, i.e., sensor embedded inside a soccer ball
- Chip held in the middle of the ball via mechanical supports

Adidas' Cairos GLT

- Uses a magnetic field to track the ball
- Cables with electric current buried in the penalty box and behind goal-line
- Cables form a grid
- Ball sensor senses and measures the magnetic grid
- Ball sensor relays the data to a computer that processes the data
- Computer declares whether ball has crossed the goal-line
- Some interesting issues
    - Ball sensor suspended to withstand impact of kicking
- Cairos GLT got its license from FIFA in February 2013
    - Allowing this technology to be provided at FIFA competitions

Inside Cairos

GoalRef

- Developed by Fraunhofer Institute for Integrated Circuits IIS
- System based on a smart ball and a magnetic field
    - Passive electronic circuit embedded in the ball
    - Magnetic field around the goal (coils embedded in the goal frame)
    - Any change in the magnetic field is detected by the coils
    - When the ball completely crosses the goal-line, magnetic field changes

FIFA tests Goal-Line Technology

Goalminder

- Developed by two football fans, Harry Barnes and Dave Parden
    - Passionate about their team, the Bolton Wanderers
    - Conceived of the system after their team was wrongly disallowed a goal
- Focuses on providing better visual evidence
    - High-speed cameras built into the goal posts and cross bar
    - Records images at 2000 frames/second
    - Delivers visual evidence to the referee within 5 seconds
    - No calibration, no automated judgement, just better evidence
- Some advantages
    - Field does not need to be dug up
    - Cameras are getting cheaper and smaller

Inspiration for Research

- Pittsburgh vs. Indianapolis playoff game (January 2006)
- With just under five and a half minutes left in the game
- Steelers' safety Polamalu picked off Colts' quarterback Peyton Manning
    - Polamalu fumbled the ball and then recovered it
    - Referee Pete Morelli ruled that Polamalu never had control of the ball
    - Ball stayed in possession of the Colts
    - Colts continued, to score a touchdown
- The NFL later said that Morelli made a bad call

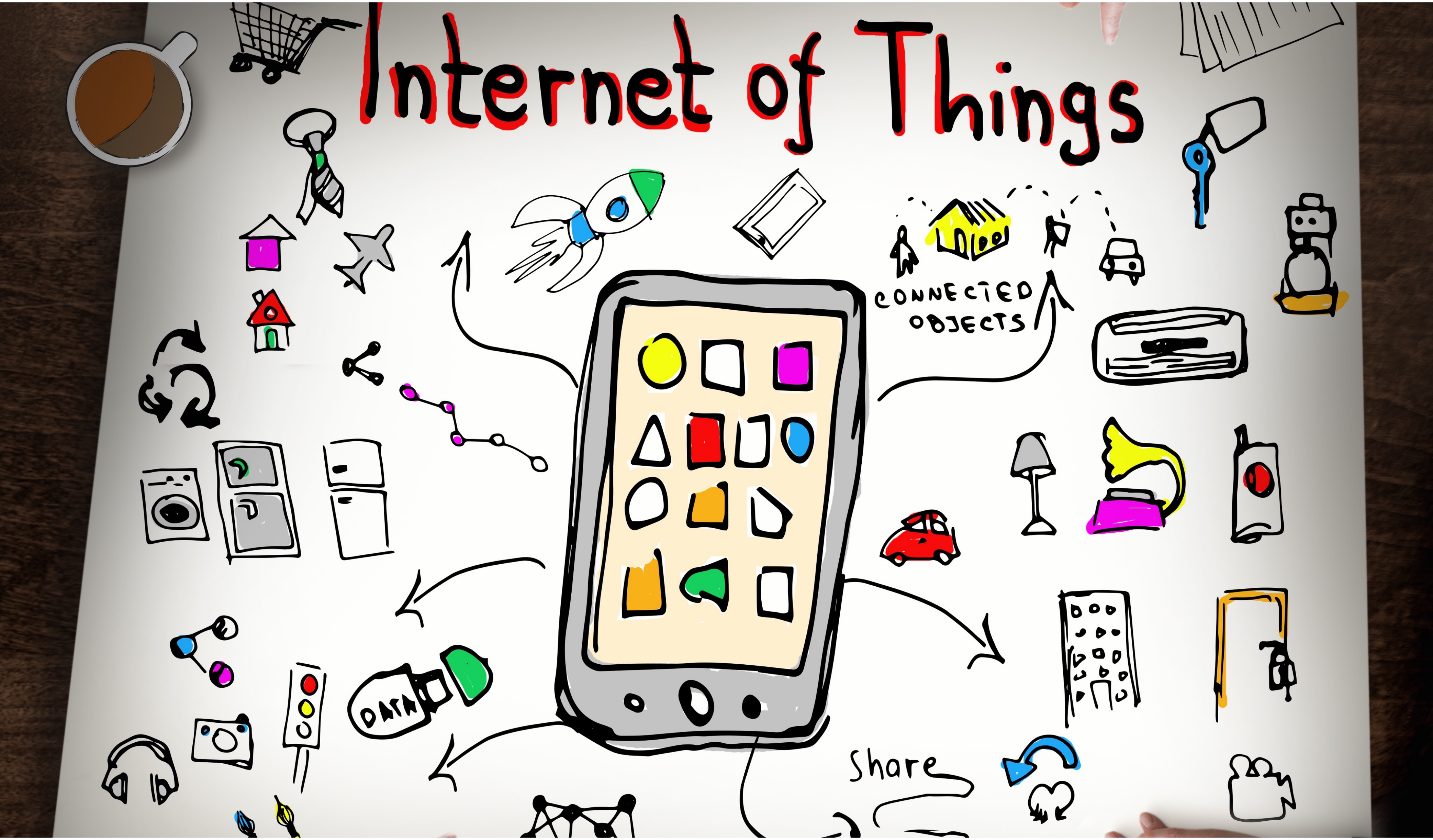
A Virtual Referee for (American) Football

- Concept
  - Using a collection of embedded devices
  - Including possibly ones mounted on the football itself
  - Possibly those mounted on players’ uniforms or knee pads
  - Possibly on different yard lines and markers on the field

- Objectives
  - Can we tell when the ball “crosses the plane” for a touchdown?
  - Can we tell when the player “does not have full control of the ball”?
  - Can we tell the difference between “4th and inches” vs. a “1st down”?

A Virtual Referee for (American) Football

- What kinds of sensors do we need?
- RFID tags? GPS devices on helmets? Accelerometers on football?
- Where do we place the sensors?
  - On the field? If so, where?
  - On the players? If so, where?
  - On the football to create an “electronic pigskin”? If so, where?
- Localization algorithms that are accurate enough to
  - Identify the location and trajectory of the football with respect to field
  - Must have sufficient resolution to pick out the football vs. players
- Ensuring the torque and weight of the football is not impacted
- Environmental conditions and their impact on the system



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