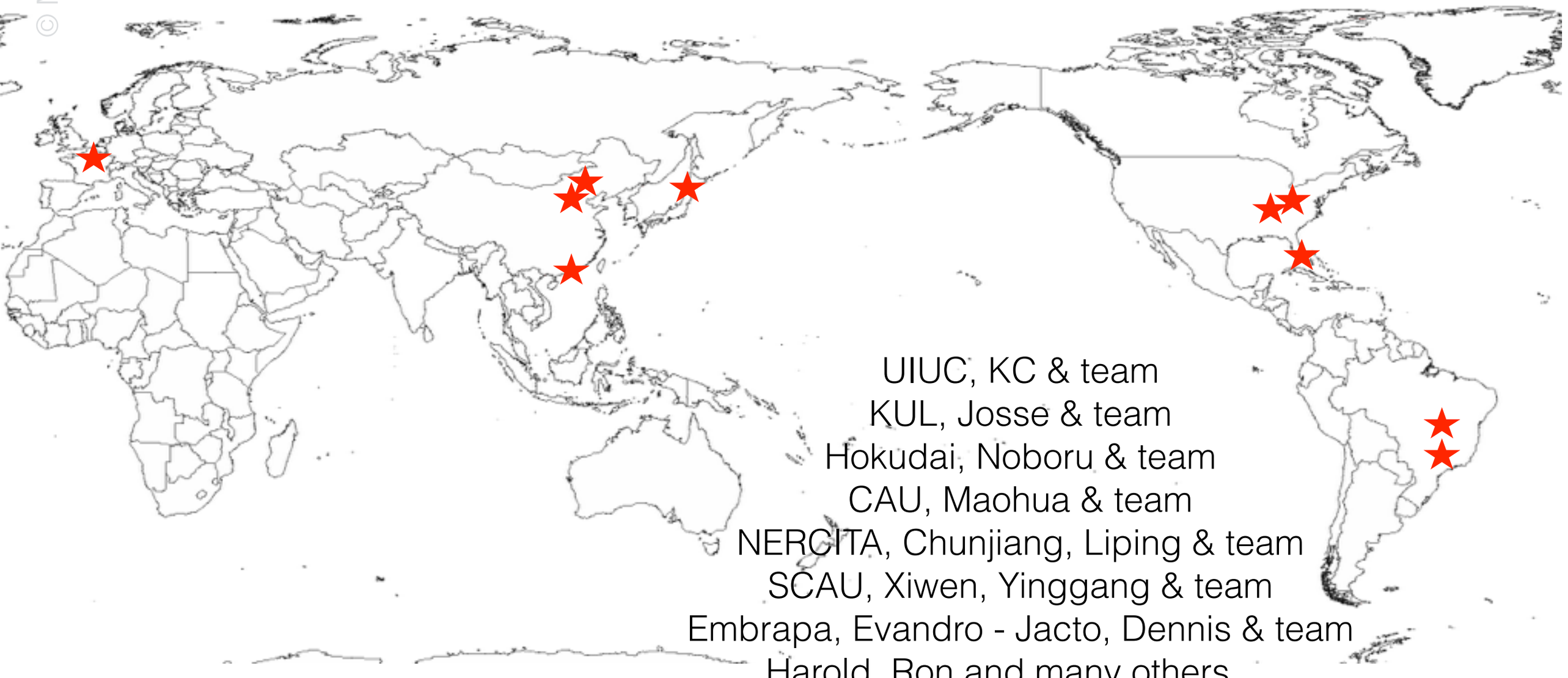
The InfoAg Conference 2015

2015 - 2035:
What's Coming for Precision Ag?

In preparing this presentation…

Many Thanks to…



UIUC, KC & team
KUL, Josse & team
Hokudai, Noboru & team
CAU, Maohua & team
NERCITA, Chunjiang, Liping & team
SCAU, Xiwen, Yinggang & team
Embrapa, Evandro - Jacto, Dennis & team
Harold, Ron and many others …
+ magazines, newspapers, books, the internet, wikipedia etc …

The two biggest challenges:
Taking good care of

Water

&

Soil

2015
International
Year of Soils

Most of everything else
we probably can make.

Belgian pears …

Dominate high end markets in Europe & Central Asia

Command premium prices

How can they do it?

Precision Agriculture !

Precision Pears: Agronomy

- Roots are pruned to control vegetative growth, but this ALSO makes trees more vulnerable to drought

—-> Precision Drip Irrigation (in between rains) to manage size & quality of pears

- Based on a **Predictive <u>Soil</u> Water Balance Model**:
    - Industry standard. **Works** reasonably well,
- But there are a few **issues**:
    - Spatial variability: location on slope, soil type, light,
    - Temporal fluctuations: when rainfall different from predictions, crop stage
    - Relevance of measuring soil moisture depends on root zone parameters (which are difficult to measure) and location of drippers

Precision Irrigation **Next**

- **<u>Plant</u> Based** Irrigation Scheduling using **sap flow monitoring**
    - Spatial and temporal limitations
- Recent discovery (Published in Dec 2013): **ReNDVI** (red edge NDVI, 705–745 nm & 770–895 nm) WorldView-2 satellite data **correlates well with stem water potential** in deficit irrigation managed pear orchards.
    - when full lit, +/- 90 min around noon time on bright days
    - using pure canopy pixels to avoid ‘contamination’ from background

Precision Pears: Future

- **Precision Fertigation:** low rate N (23 # / ac), 6 weeks before harvest, gives bigger fruit & better color. Replicated science based !

- Structured program of moisture surveillance and **Precision Irrigation** using drones & ReNDVI sensors

- ~ 5 years (?): **Precision Robots** for flower pruning

- ~ 10 years (?): **Harvesting Robots** for narrow curtain type trees

Who contributes ? (random order)

- Many entrepreneurial & innovative **farmers**
- Packers & auction **companies** (cooperative and private)
    - Bel'Orta, Veiling Borgloon, Veiling St. Truiden…
- **University** of Leuven (KU Leuven)
    - Pol Coppin, Jan Diels, Ben Somers, Wouter Saeys, Laurent Tits, Jonathan Van Beek, Jan Vanderborght, Hilde Vandendriessche, Josse De Baerdemaeker
- National PCFruit **Research** Station
    - Tom Deckers, Hilde Schoofs, Wim Verjans
- **Soil Service** of Belgium
    - Pieter Janssen, Annemie Elsen, Frank Elsen, Wendy Odeurs, Hilde Vandendriessche

Belgian Pears & P.A.

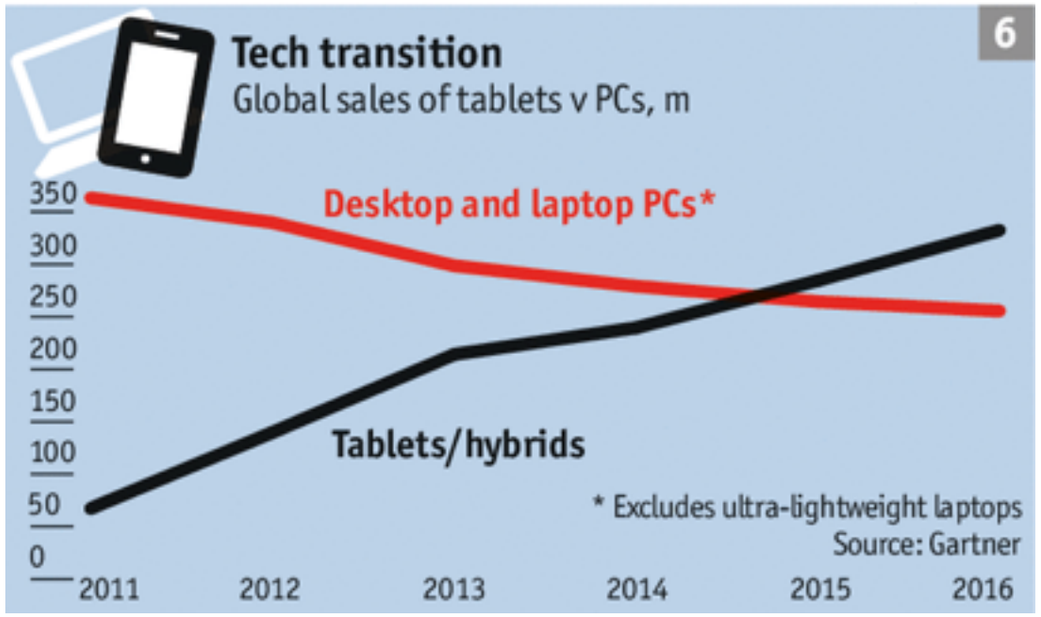
- P.A. is also for small niche markets
- P.A. is also for quality driven produce
- Evolving P.A. maintains Belgain pear grower's market leadership

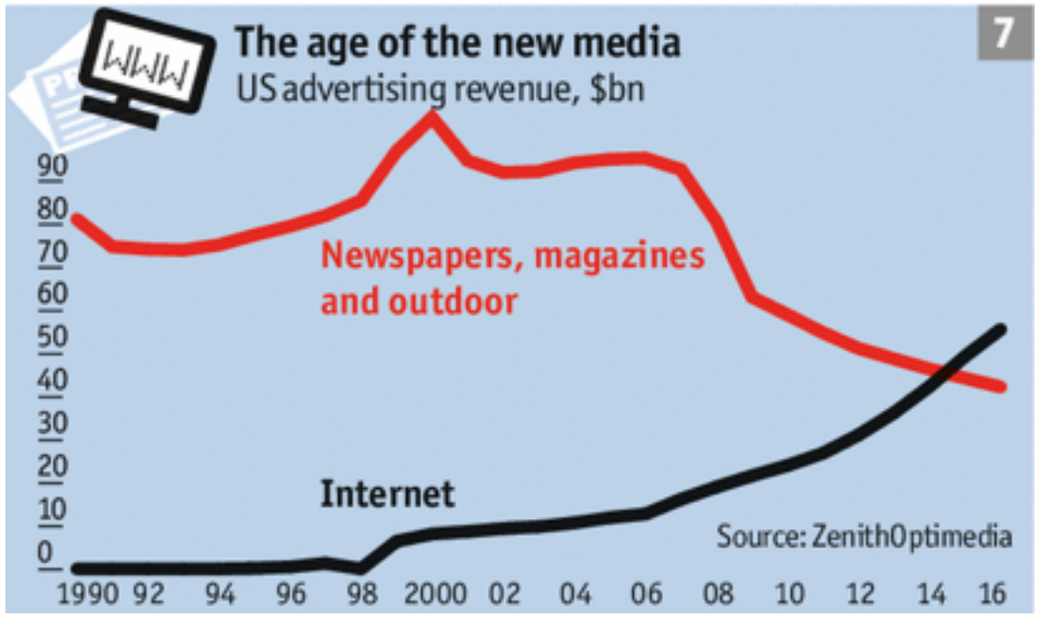
Background:
In what environment will P.A. evolve?

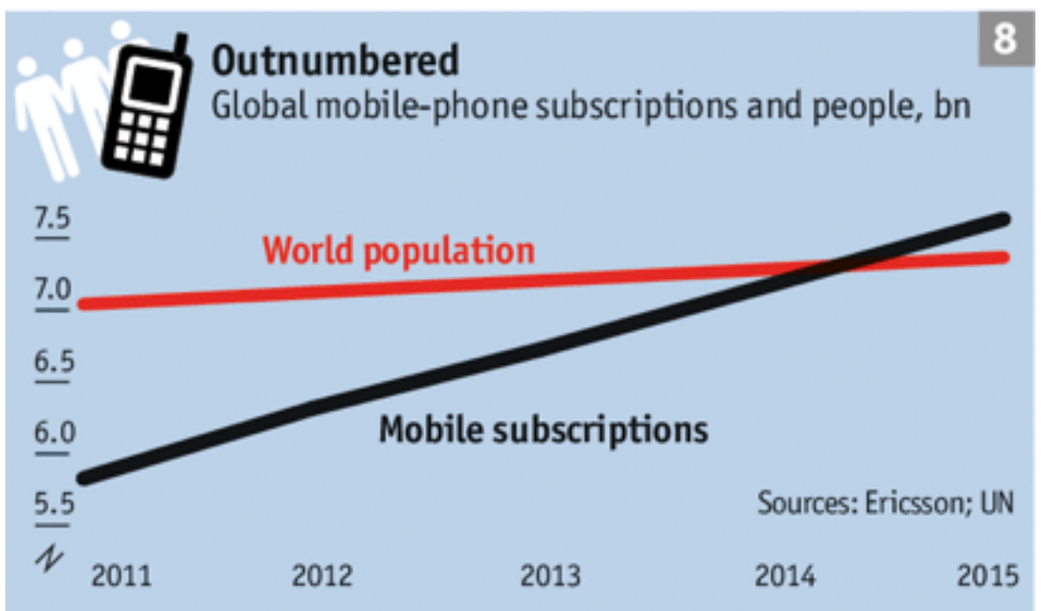
A rapidly changing world
Tertulian, Malthus & Ehrlich
Moore, Cooper & Haitz

Rapidly Changing World

2014-15 Internet Crossovers…

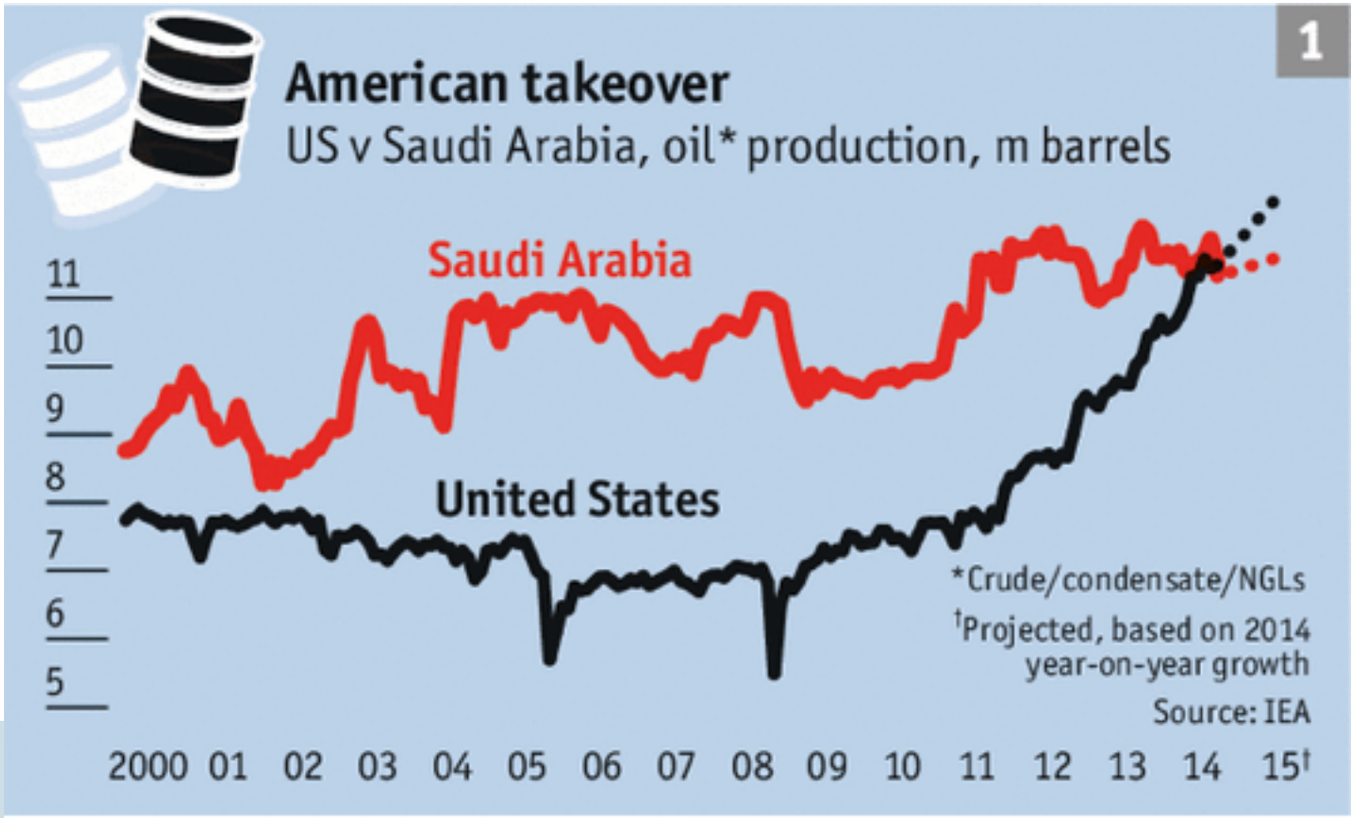


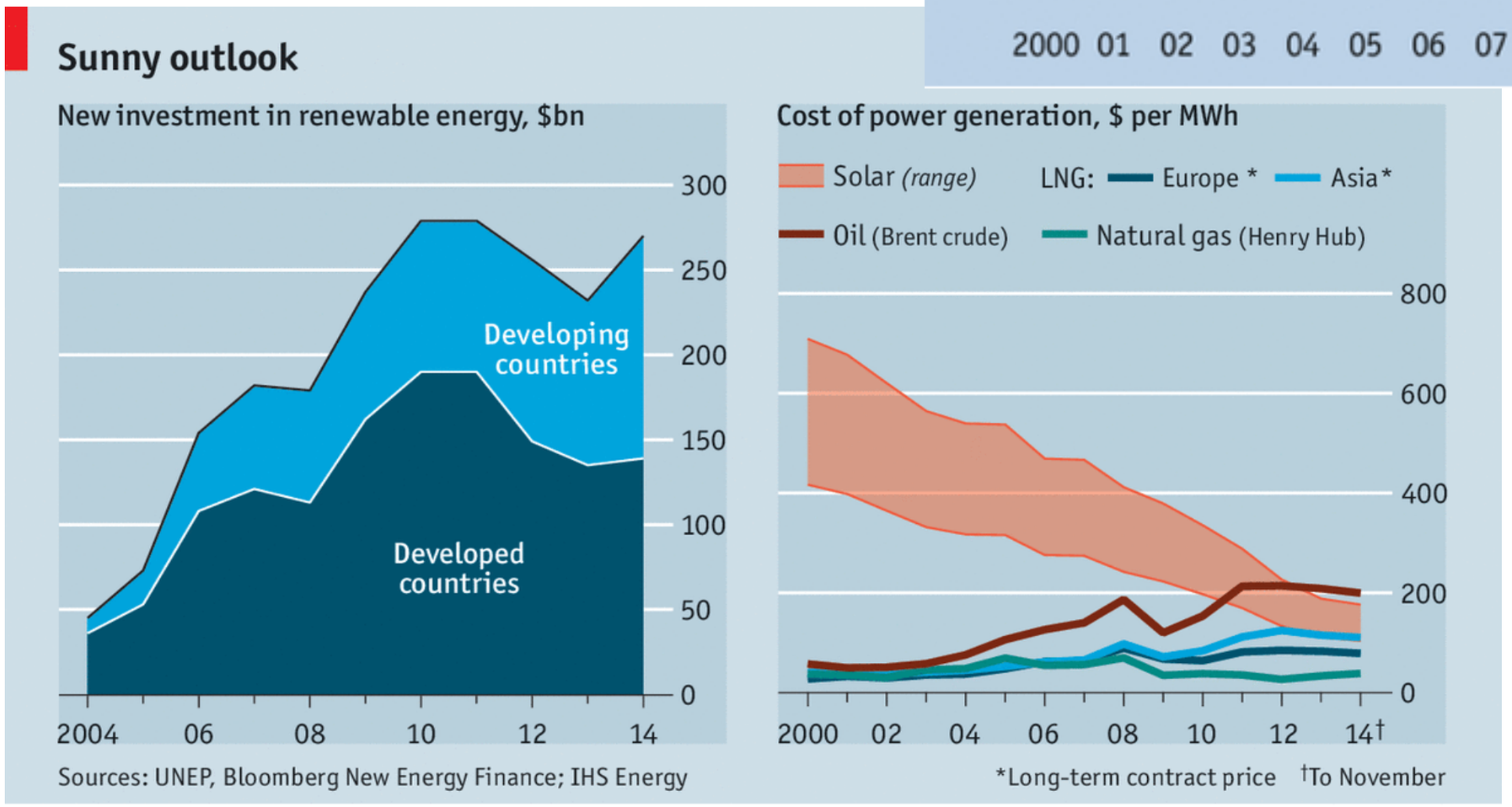




- globally more tablets than desktops
- US advertising revenue
- globally more mobiles than people

Energy …

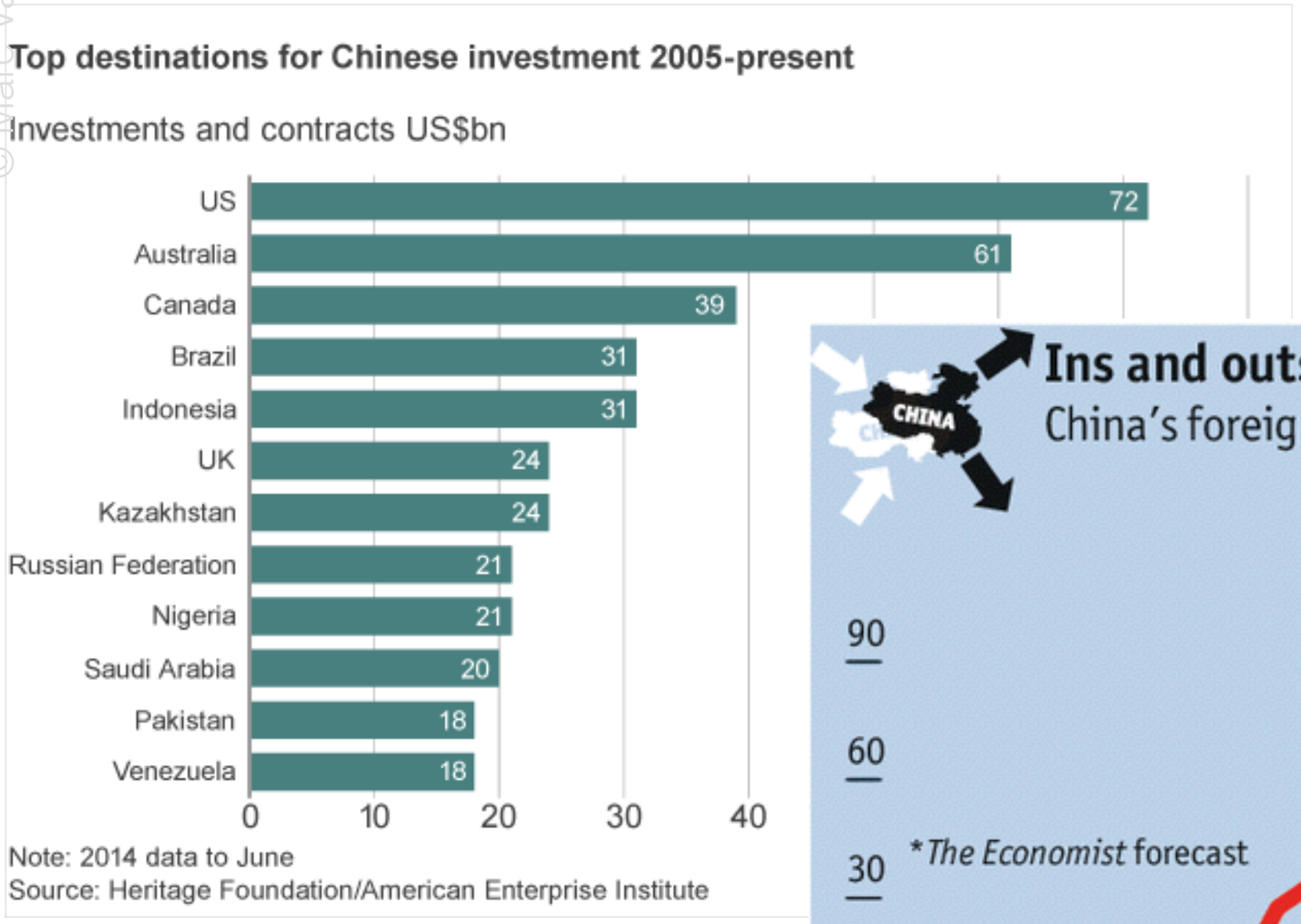


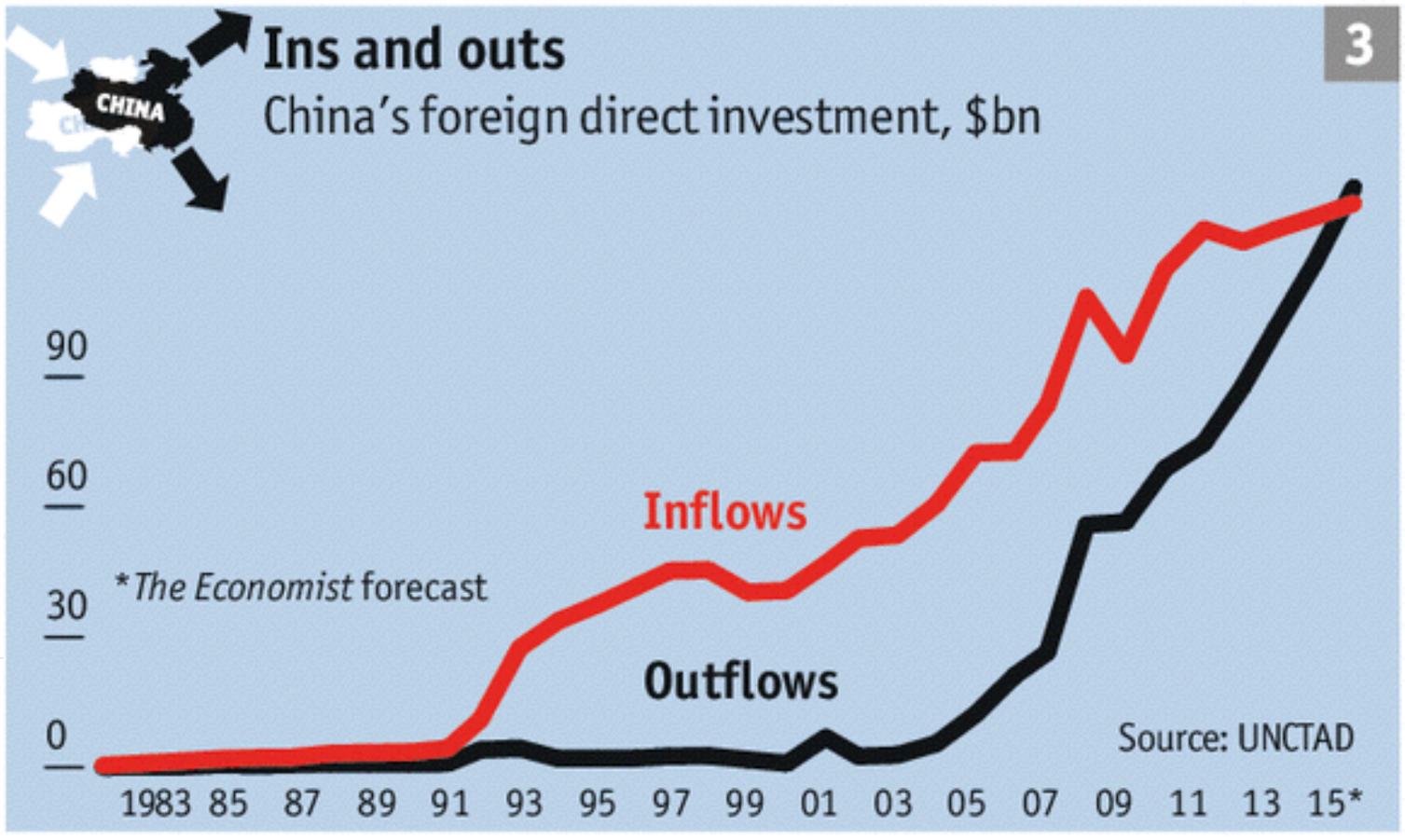


Economist.com

Changes in … where it comes from, & what generates it.

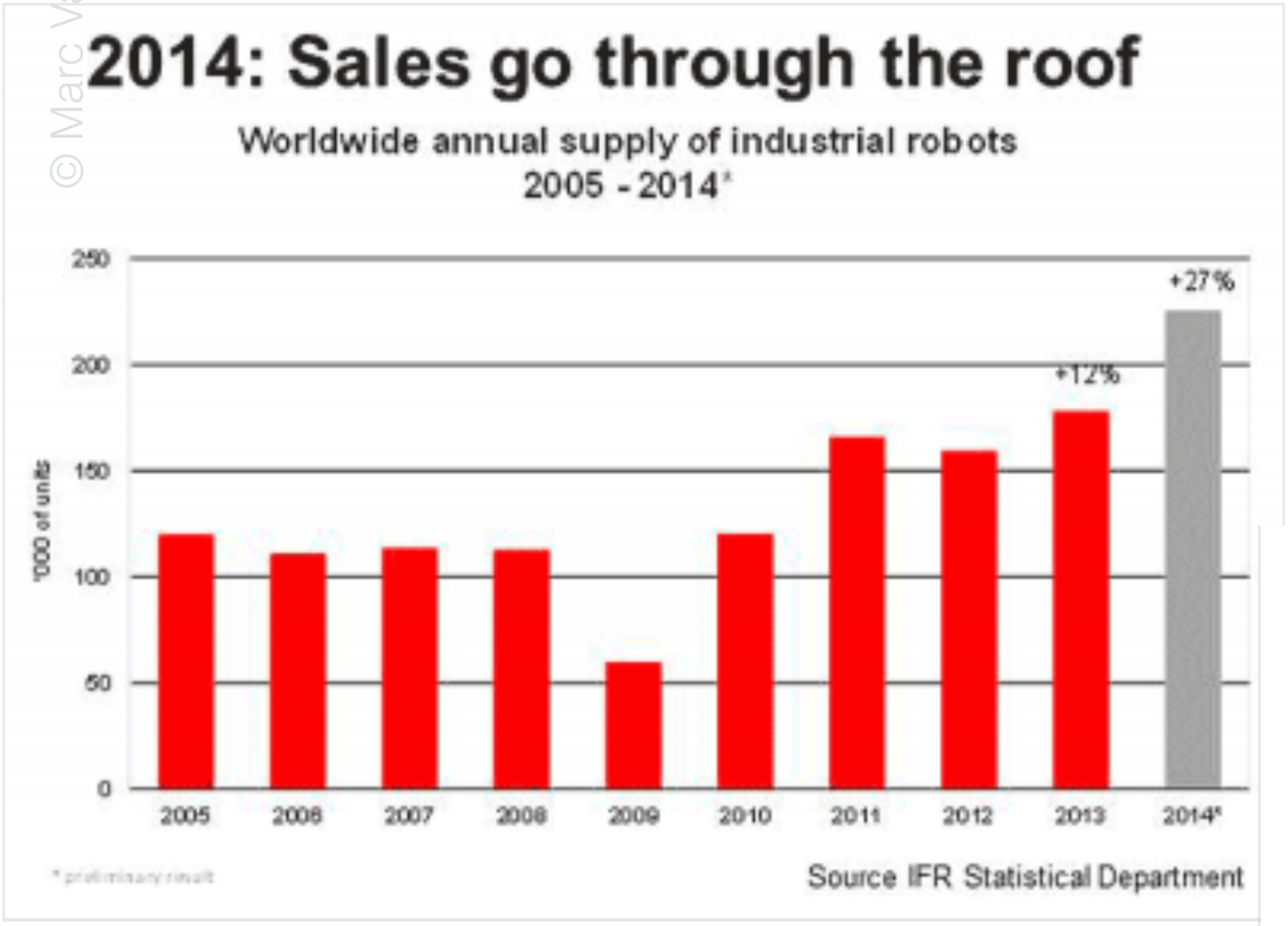
Investments: a two way street

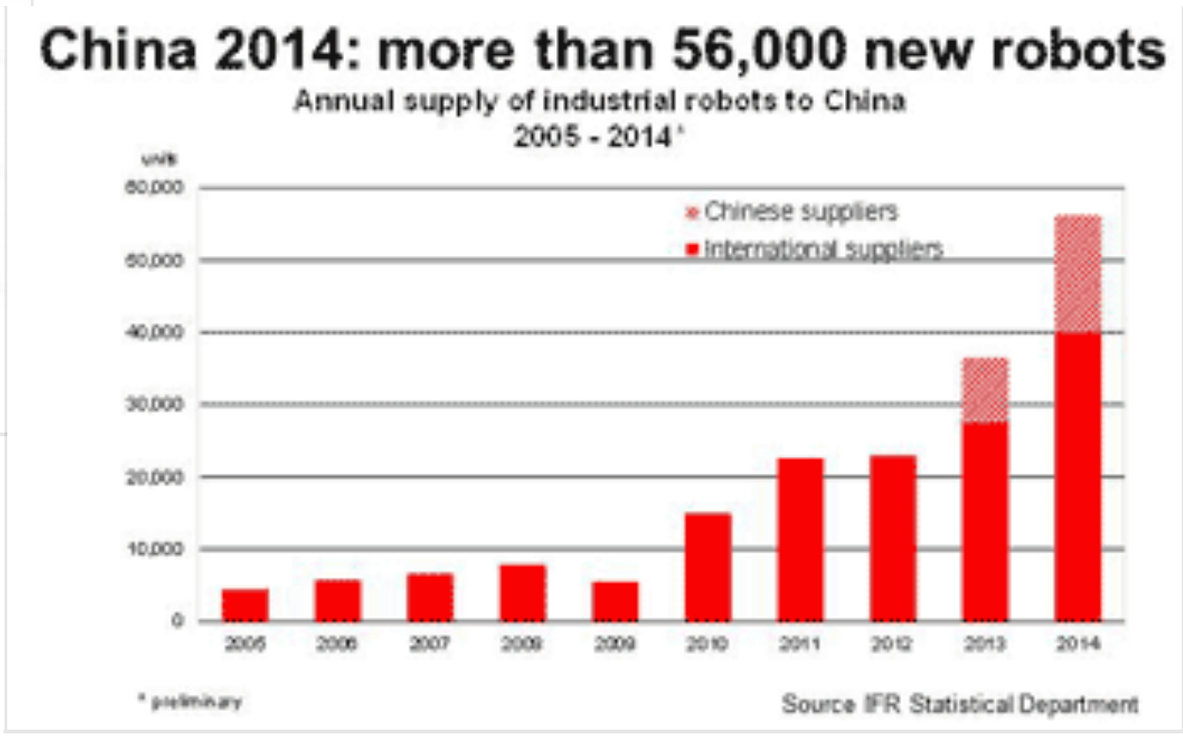




China invests abroad, & the US is the leading destination

No longer low salary…





China is now a major buyer & producer of industrial robots

Learning development

Too many cars are not good for mobility, Xi’an, China

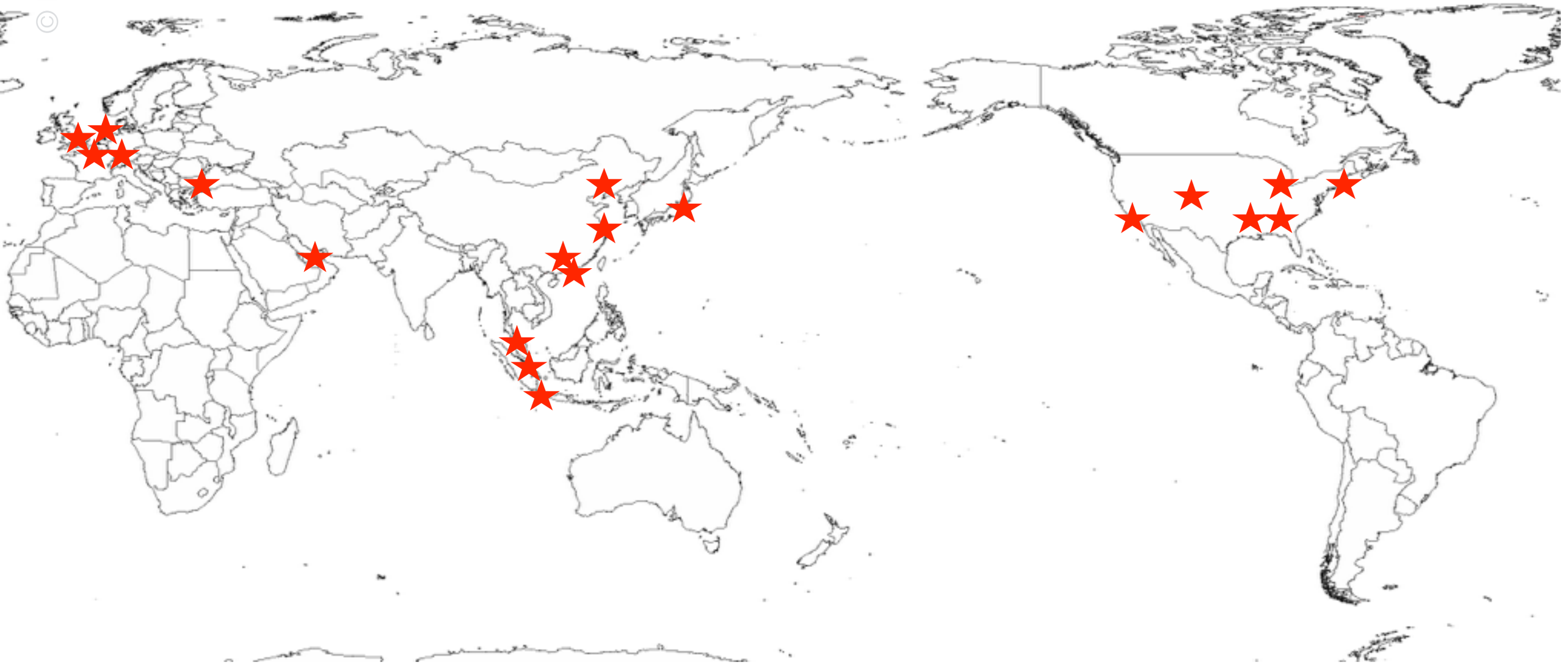
Learning development

Too much fertilizer is not good for beach tourism, Qingdao, China

Top 20 airports 2000

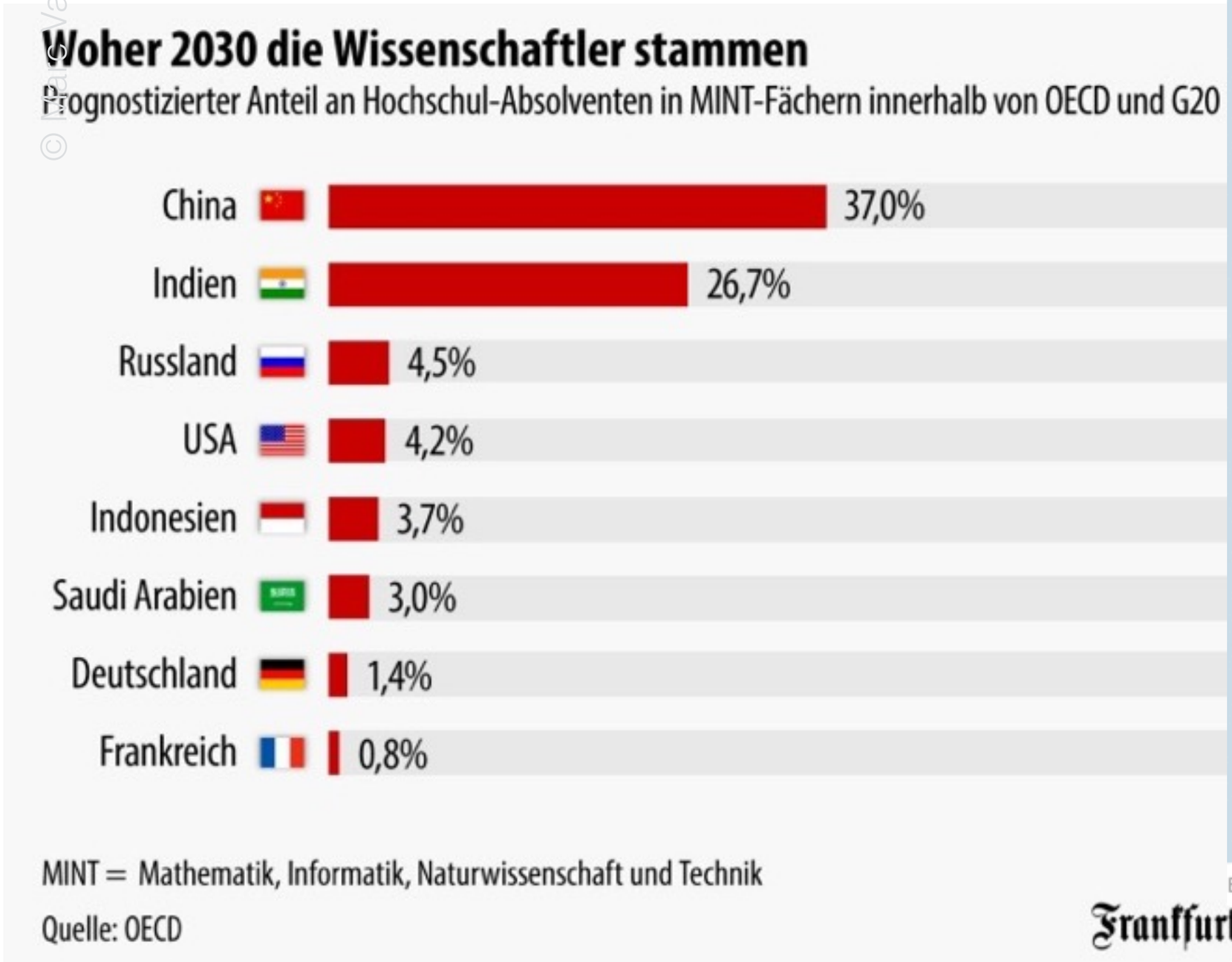
2000 Air traffic mainly Atlantic and Japan

Top 20 airports 2014



2014: Half of major airports are now in Asia & M.E.

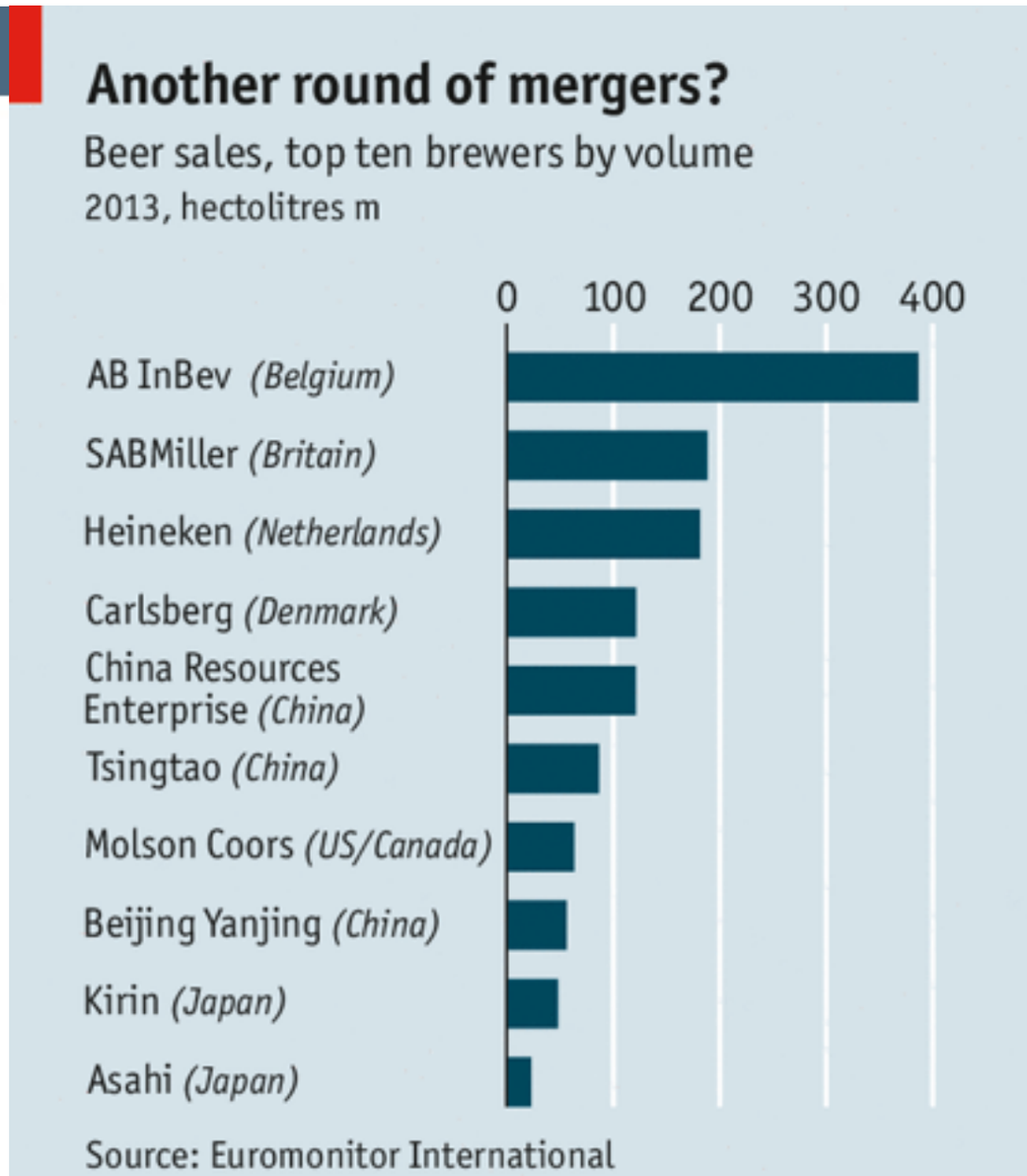
STEM & Patents



Frankfurter Allgemeine statista

Shifting Origins of scientists. Immigrants file a lot of patents!

Changing tastes …
in a global market



Leapfrog ? 😉

Zhangjiakou, Hebei, China

Changes: Conclusion

- Precision Agriculture will go …
- where economies grow
- where consumers want it
- where engineers & agronomists work on it

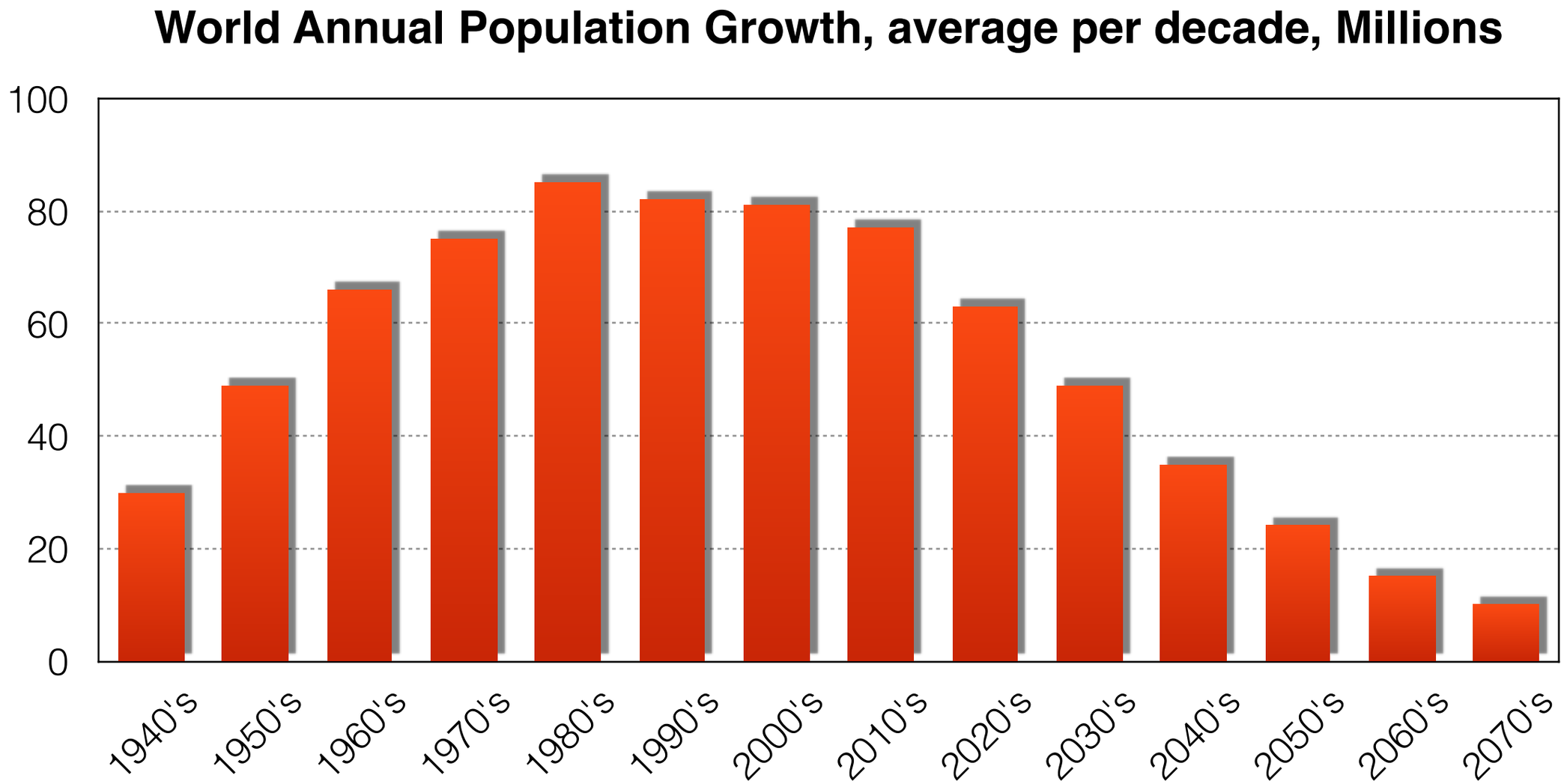
World population growth

Gloomy predictions by
Tertullian, Malthus and Paul Ehrlich
were wrong,
fortunately

Grow to hunger ?

- Gloomy predictions based on the (supposed) gap between
    - **linear** growth of food production vs.
    - **exponential** growth of populations
- Most frequently quoted:
    - Tertullian, 3d century AD, Church leader
    - Malthus, 1789, demographer
    - Paul Ehrlich, 1968, Stanford University Biologist

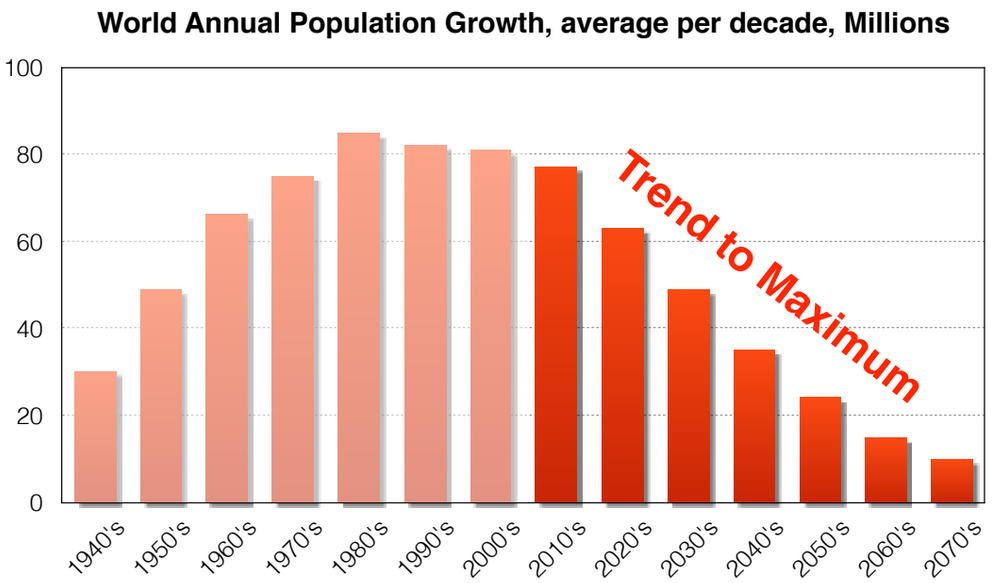
Population Growth: Facts



We know when and at what level the world population will stop growing.

How do we know?

Population Growth: Facts



Source: FAO

- Science of Demographics
- Fertility has dropped sharply in all areas, even Africa.
- In many countries fertility is now below replacement (2.1)
- Most women giving birth on the chart have already been born !

Growth in food demand

- The World has to grow food / feed production by 60-70 % to feed 33% more people.

- Production must grow LINEAR ~2 % / year (~1.5 % if we better manage current 30% food waste)

- This is in line with past performance (which admittedly caused stress on soil & water resources).

- It can be done, but we have to be better at how we do it!

"Overall, feeding the world has become much more manageable."
Dr. Josef Schmidhuber, former head of the Global Perspective Studies Unit at FAO.

Population: Conclusion

- P.A. helped grow food effectively & efficiently the last 20 years

- P.A. will be even more important to help grow food effectively & efficiently the next 20 years

- P.A. will be the bridge

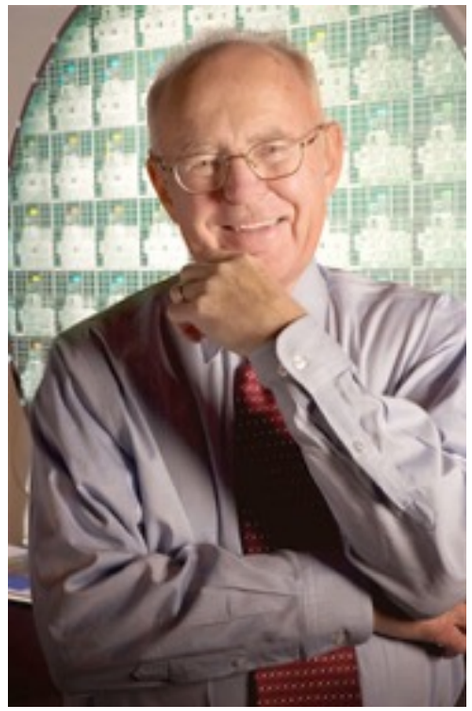
    - between **scale & quality**

    - between **productivity & sustainability**

Laws of Technology

Moore's Law: transistors on chips
Cooper's Law: wireless communications
Haitz's Law: LED light

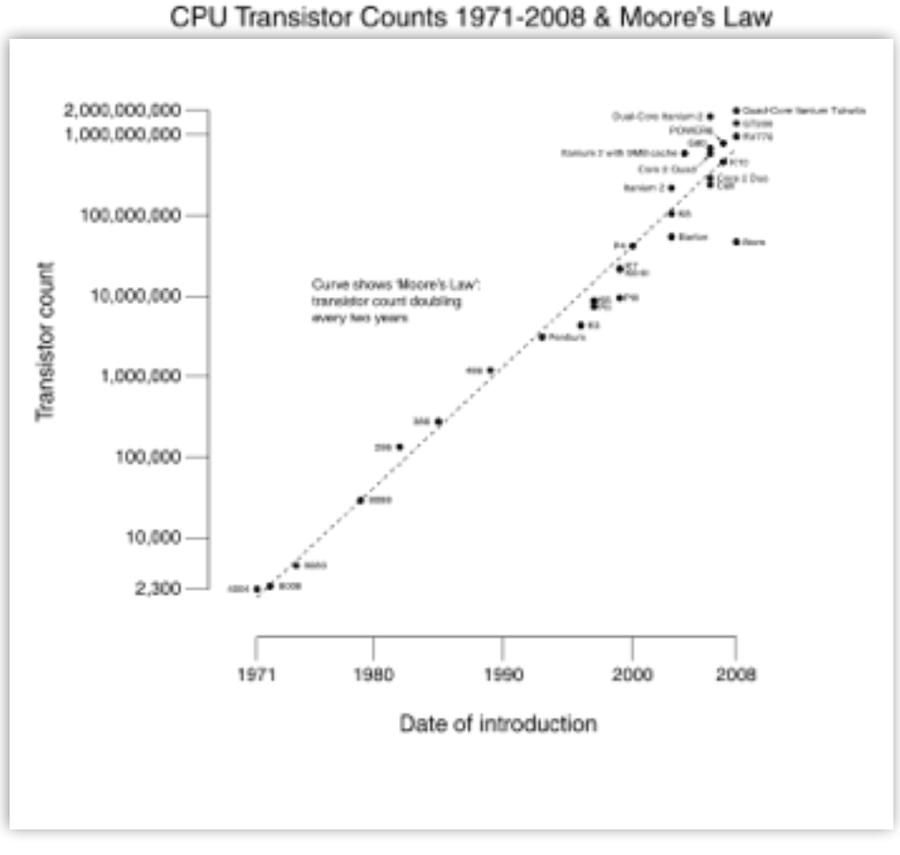
Moore’s Law



Gordon Moore,
Former Fairchild ,
Co-founder Intel

- Gordon E. Moore introduced the concept in a 1965 paper.

- The **number of transistors** that can be placed **inexpensively** on an **integrated circuit** has **doubled** approximately every **two years**.



The end in sight? **NO**

Source: Scientific American, May 2015, p 58-63

New technologies for miniaturization, lower cost & higher power

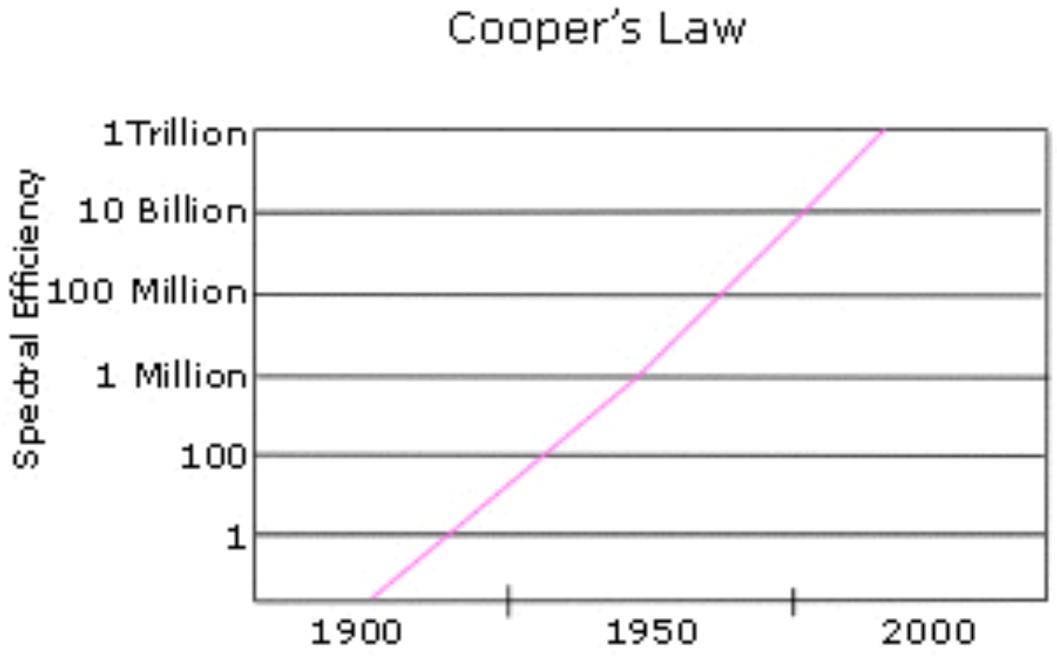
- IBM's 7 nm chip presented July 9. 2015
- memristors
- carbon nanotubes
- switch from 'von Neumann architecture' to architectures without 'bus'
- heterogeneous computing combining different architectures

Cooper's Law

Martin Cooper,
inventor of the celphone,
ex Motorola,
now ArrayCom

The number of voice or data "conversations" theoretically possible in a given area over all of the useful radio spectrum has

- doubled
- every two-and-a-half years
- for the past 104 years.



Cooper's Law…

	~1985	~1995 GSM	~2005 3G -	~2015 4G-LTE	~2025 … 5G
Basic	Analog	Digital	—->		
Switching		Circuit switching	Packet switching	—->	
Protocols				I.P. protocols	—->
Capacity					MIMO (Antennae) Carrier aggregation
Latency	N/A	N/A	500 millisec	50 millisec	< 5 millisec
Data Speed	Zero	zero	~100 **K**bps	10-100 **M**bps	> **G**bps
Issue ?					Microcells Rural issue?
Tel. Modems	Do you remember?	Max 76 **K**bps			

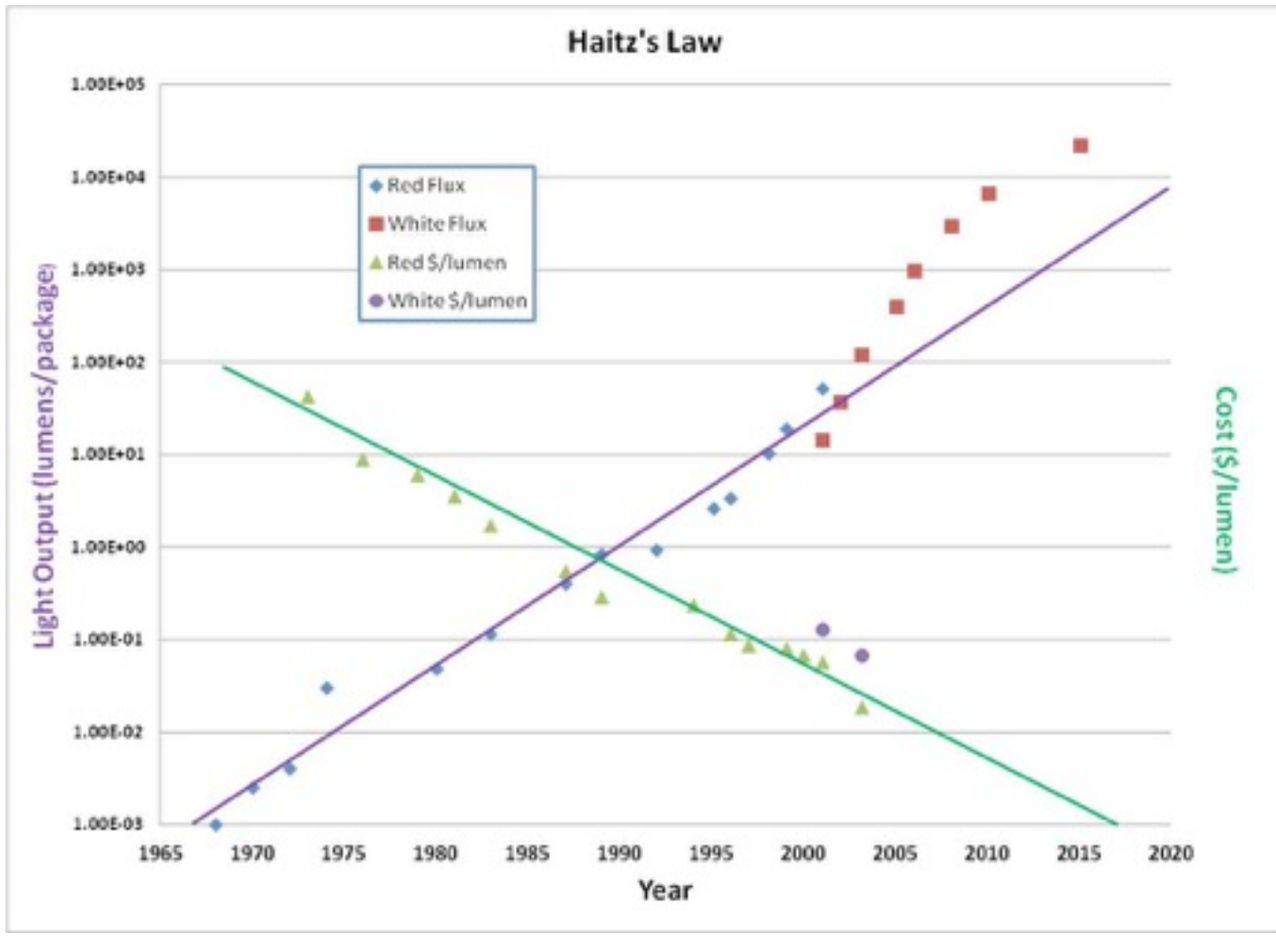
Haitz's Law

Dr. Roland Haitz
Engineer at H.P.,
now Agilent
Optical Sciences

- The amount of light that can be produced per LED diode

- increases 20-fold every decade,

- while the cost of that light decreases 10-fold.



Haitz & Precision Agriculture

- Stronger & cheaper LED's mean:
  - Active sensors
  - High efficiency greenhouses
  - Vertical / Enclosed farming

Is world's largest indoor farm the way of the future? - The Washington Post

Is world's largest indoor farm the way of the future?

A worker at the indoor lettuce farm in Japan. General Electric photo.

The 3 laws and P.A.:

- P.A. initially was enabled by Moore's Law (Pentium Chip & Mapping software)

- P.A. expanded with Cooper's Law (smartphones, tablets and telemetry)

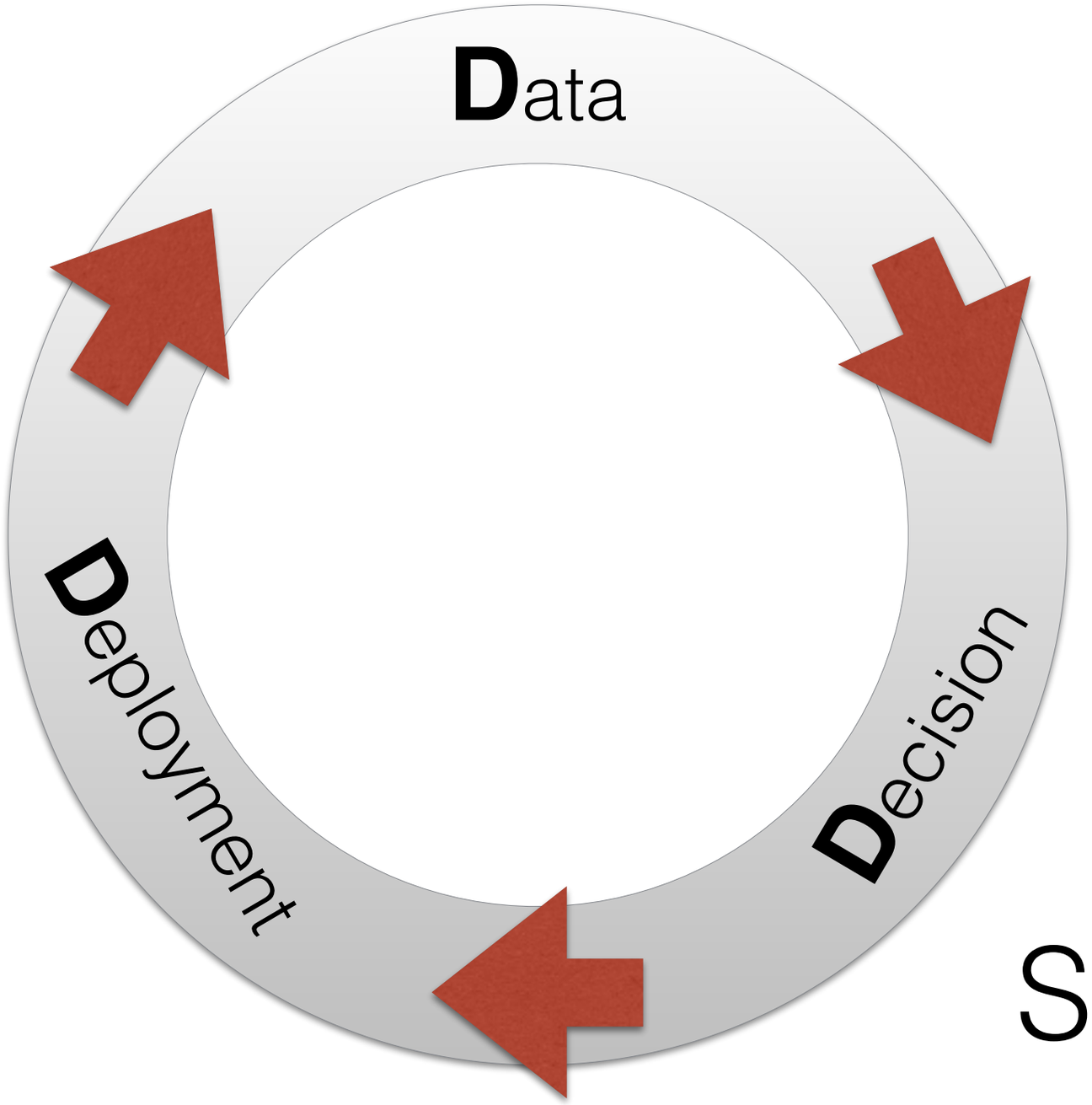
- P.A. will continue growing benefiting from Haitz's Law (active sensors & controled environment agriculture)

Technology: Conclusion

- If it can be built into a car…
    - if you can wear it on your wrist…
        - if it can manage your house…
            - if it can track your health…
                - and keep you entertained …
- Precision Agriculture will use it to
    - grow **5 F** - **F**ood - **F**eed - **F**uel - **F**iber - **F**un
    - **effectively, efficiently and sustainably**.

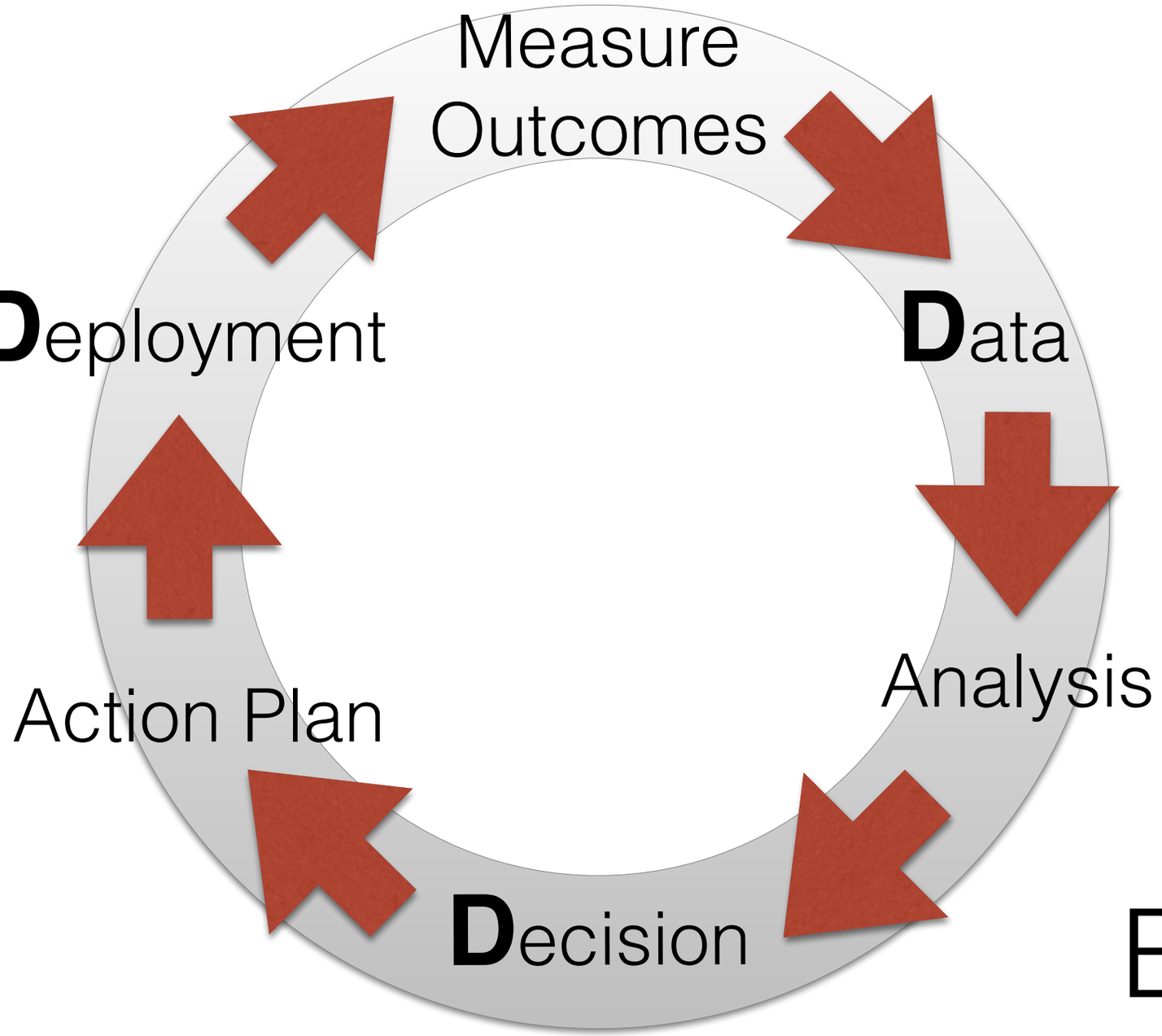
Precision Agriculture
&
Decision Cycles

Information Cycle in 3 D



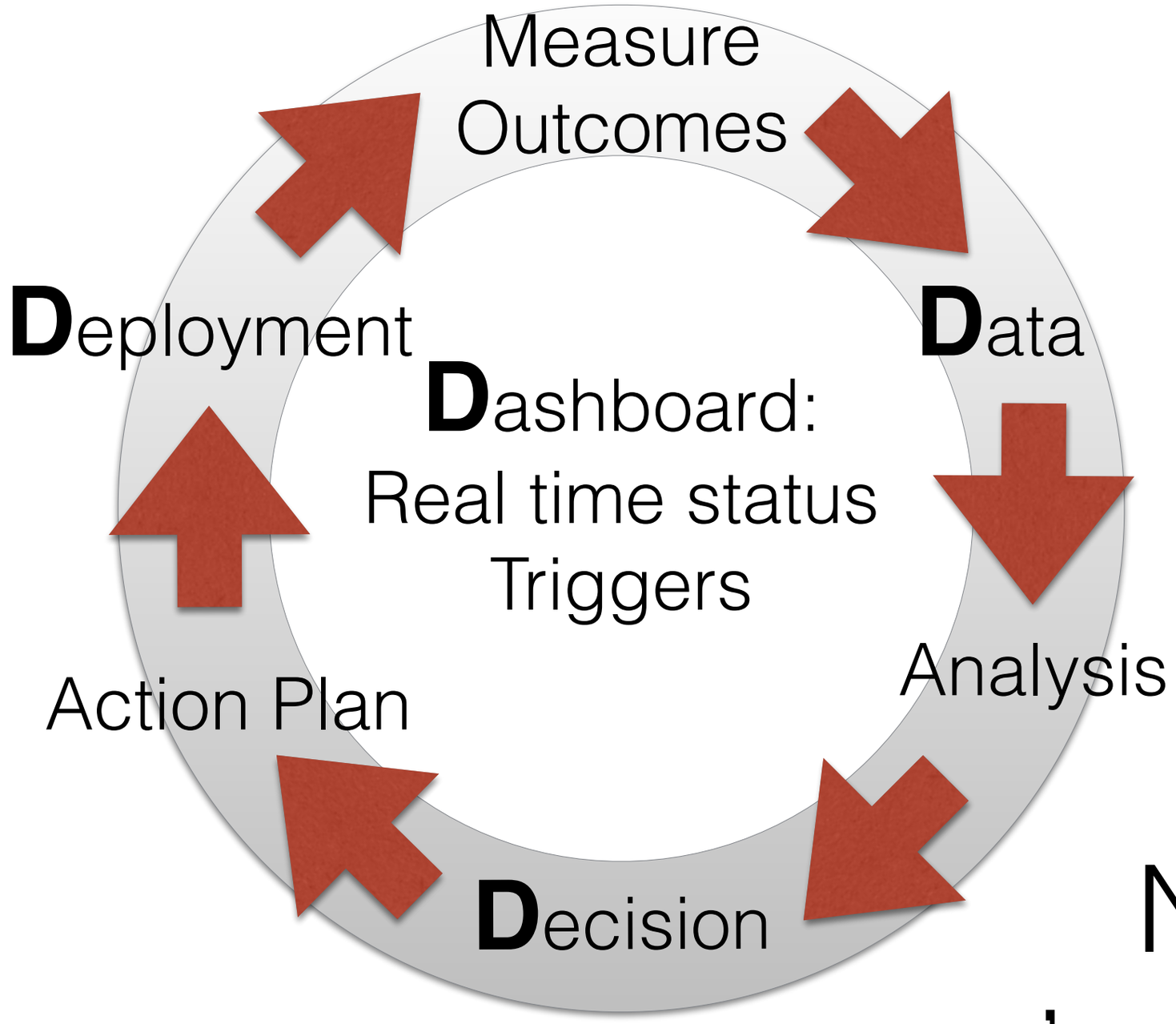
Too Simple?

Information Cycle in 3 D



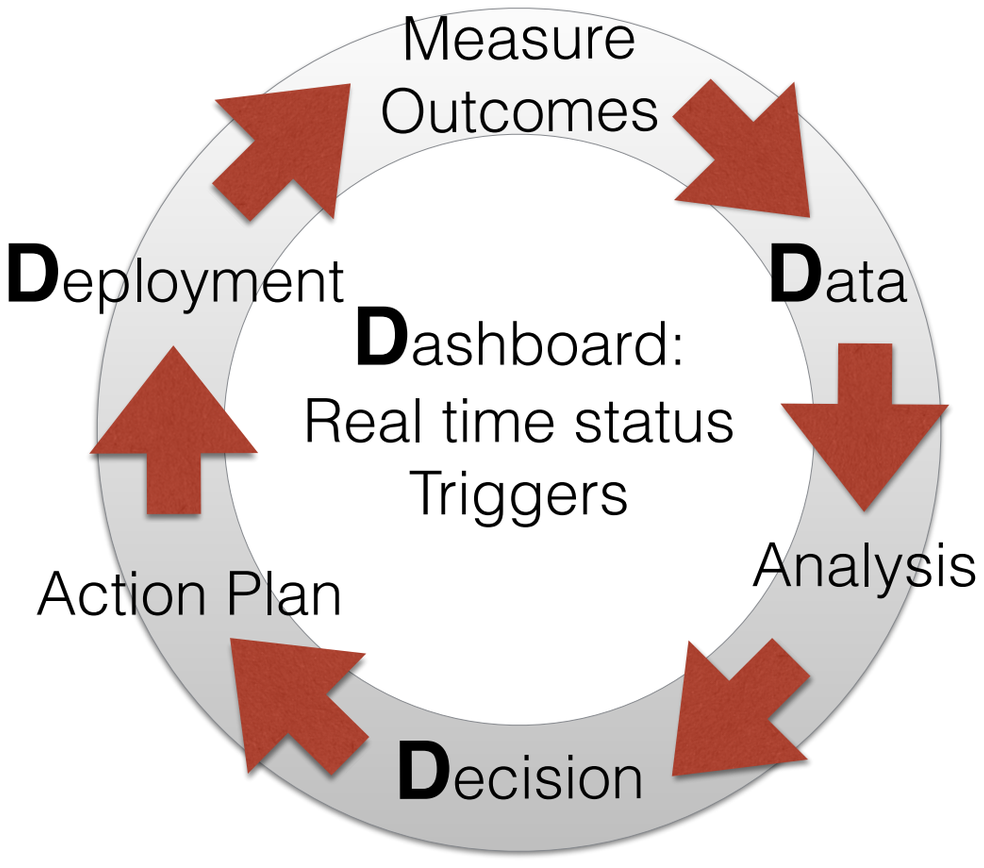
Better?

Management Cycle in **4 D**



Now
we're talking !

Decision cycles: N Example



- A sensor on a drone ‘sees’ variability of ‘greenness’.
- That leads to a variable rate N recommendation and application
- We send out the drone again after the application to measure the immediate (2-5 days) and delayed (10-14 days) reaction of the plants to the treatment
- At harvest we measure the ultimate outcome in bushels.
- We compare the 4 maps/images to learn about N / plant interaction.

Innovations

Ongoing & future

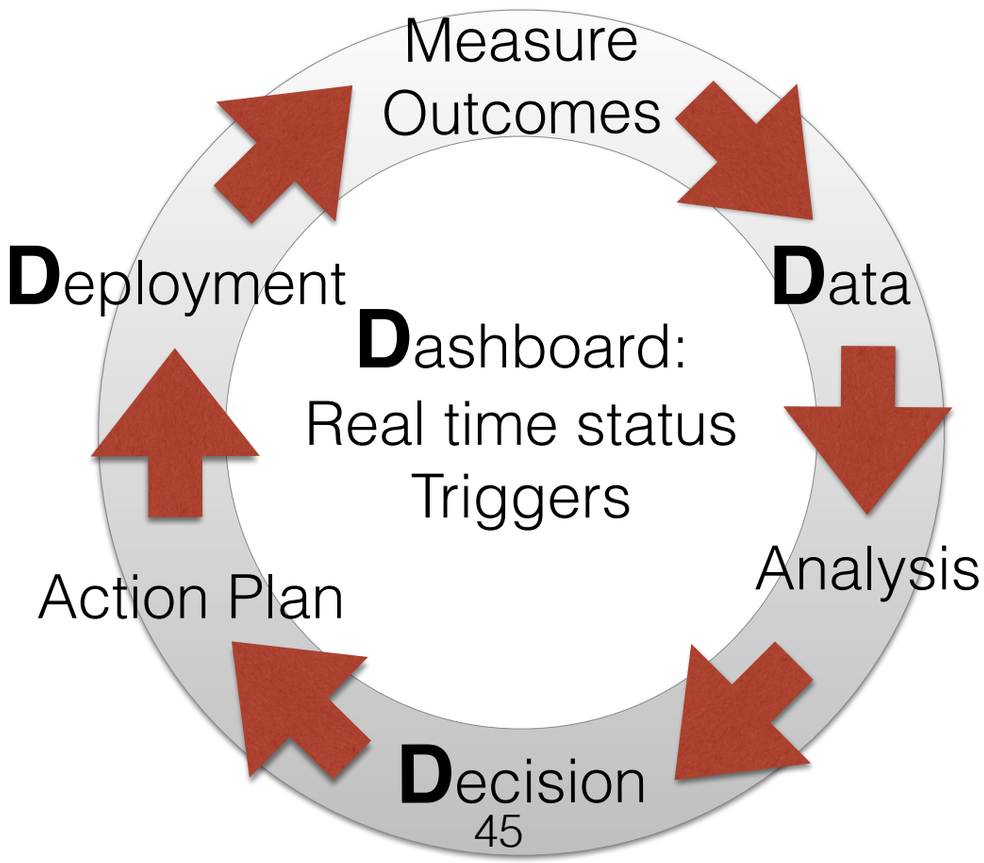
Ongoing & Future Innovations

Measuring & Data Tools

Visual-NRI-Multispectral-Fluorescence
Real time soil measurements
Tools for human scouts
Soil Sampler Robots
Digital Insect Traps
Sensor Platforms
Sensor Networks

Deployment Tools

Autosteer
V.R. Seeding
V.R. Sprayers
V.R. Irrigation
V.R. Spreaders
Telematics (Eqt.)
In-crop treatments
Telematics (Agronomy)
Autonomous Grain Cart



Analysis & Decision Tools

Weather data
Product libraries
Digital Soil Maps
Wireless networks
N dynamics models
Crop growth models
Field Boundary Data
Cloud based Services
Satellite Images Analysis

Measuring / **D**ata tools

NRI		Holland Sc., Cropcircle, Yara. CAU, Nercita…
Visual		Many, Spectrum App. for N, CAU, Nercita…
Multispectral		Tetracam, Dycam, CAU, Nercita…
Fluorescence		Force-A
Sensor Platforms		Satellite, Fixed wing, Helicopter, Spray boom, Rowbots, Roboats, Hoverboards
Sensor Networks		ZIGBEE, CAU, Nercita… other protocols
Digital Insect Traps		Spensa
Soil Sampler Robots		Falcon, Magictec, Agrobotics, GVM, Nercita…
Tools for human scouts		Smartphones, Tablets, custom, CAU, Nercita…
Real time soil measurements		Veris, Geonics, SI Seiko, CAU, Nercita …

Analysis / **D**ecision Tools

Weather data	Climate Corp, DTN, Iteris, ZedX, …
Product libraries	Agrian, CDMS, Icama, Nercita,
Digital Soil Maps	USDA/NRCS, Private packages
Wireless networks	G3, G4, LTE, Nercita…
N dynamics models	Universities (MRTN), IPNI (Nugis)…
Crop growth models	Universities, consultants, Geosys, Nugis
Field Boundary Data	USDA, Climate Corp.,
Cloud based Services	Many, Nercita
Satellite Imagery Analysis	GeoSys, RapidEye, DigitalGlobe, Hitachi, Nercita

Deployment Tools

Autosteer	Deere, Trimble, Outback, Topcon, Leica, SCAU, Nercita …
V.R. Seeding	Precision Planting, Deere, Kinze, SCAU…
V.R. Sprayers	Y-360, Norac, Capstan, Hagie, Deere, Nercita
V.R. Irrigation	Deere, Valley Irrigation, …
V.R. Spreaders	Jacto, Hagie, AgCo-AgChem, NewLeader
Telematics (Eqt.)	All Eqt. manufacturers, Nercita
In-crop treatments	Jacto, Y-360, Norac
Telematics (Agronomy)	Farmobile, Slingshot, Mueller, Trimble, Nercita
Autonomous Grain Cart	Kinze

Precision Agriculture Future Concepts

Navigation, Telemetry & Self drive
Sensors
UAV's
Agricultural Equipment
TIOT, Networks & CEA
Big Data & System Integration

Navigation, Telemetry
&
Self drive

Navigation —> Self drive

Exhibit 22: Steps toward full self-drive automation
Four autonomous driving levels

Autonomous Lv.	Outline	System
Level 1	Either one of the acceleration/handling/control would be done by automobile.	Safety assistance
Level 2	Either 2-3 of the acceleration/handling/control would be done by automobile.	Semi-autonomous driving
Level 3	The acceleration/handling/control would be done by automobile and a driver could take over control in emergency situation.	Semi-autonomous driving
Level 4	The acceleration/handling/control would be done by automobile and no involvment of a driver.	Autonomous driving

Source:: Goldman Sachs Global Investment Research.

- Goldman Sachs' 4 levels
- Not 'if?' but when?
- DARPA & car industry
- Real Implemetations
- Legal and regulatory framework.

Examples: Trucks

Driverless convoy: Will truckers lose out to software?

Living the dream: Daimler's new autonomous lorries drive themselves while the safety driver can read a book, watch the game or write a bestseller

Sleepiness and stress are perennial risks for the long distance lorry driver, and accidents are sadly too frequent.

However, a radical new driverless truck being trialled by Daimler may offer a solution.

Examples: G.I. Joe

Driverless convoy: Will truckers lose out to software? - BBC News 5/26/2015, 16:13

This military vehicle, the SMSS can track a single soldier, transport supplies over rough terrain and carry out casualty evacuations

Example: airport shuttle

Vlaanderen krijgt binnen drie jaar eerste zelfrijdende lijnbus

De Lijn zal in 2018 een eerste zelfrijdende bus inzetten op een parcours rond de luchthaven van Zaventem. Het gaat om een proefproject, waarmee de openbaarvervoermaatschappij wil vermijden dat de autosector een kapitale voorsprong neemt.

Conclusion on Self-Drive

- It will happen !
- Long before 2035 most people will have experience with self driven vehicles
- By 2025 most field equipment in agriculture will have built in capability to ‘self operate’
- Many will have this capability actually enabled / used.
- Telemetry will make ‘self-operating’ palatable

Question on Telemetry

- Telemetry is VERY useful to keep an individual fleet of vehicles at operating capacity.
- It also gives the manufacturer macro information (how many planters / combines are active when & where)
- Today, this macro data is **not** used / analysed / sold
- How will this data be managed in the (near & distant) future ?
- We already see differential car insurance premiums based on actual driver behavior, measured by ‘recorders’ in cars.
- Will telemetry cause differential loan / lease conditions in ag. ?

Sensors

Ubiquitous & Invisible

Sensors in an iPhone 6

- Proximity sensor
- Accelerometer
- Ambient light sensor
- Gyroscopic sensor
- Magnetometer
- Compass
- Orientation sensor
- Barometer

What will we measure?

- Plants (crop growth, crop health, phenotyping…)
- Spatial variability:
    - soil (type, characteristics), slope, roots
- Temporal fluctuations:
    - weather, cumulative effect of weather, pests & diseases and fertility (mostly N)
- Interactions between soil, crop & weather

How will we measure?

- **Full census** data when/where we can,
    - **Sample** data if we have no alternative
- **Directly**, via a **stand-in** or via a **model**
- **Single source** or through **data fusion**
- **Proximal** or **Remote**

Many technologies

- Visual, NIR, IR, temperature
- Absorption, reflection, scatter
- LIDAR, Fluorescence, Terahertz tomography
- Embedded biochemical sensors and markers
- Data from equipment telemetry
- Sap flow (in the plant or remotely)

Will we ‘sense’ … near Real Time and near Census Intensity … ?

Crop stress

Crop health / maturity

Stressor identification

Soil structure,

chemistry, fertility

moisture,

microbiome

Will we ‘sense’ … near Real Time and near Census Intensity … ?

Crop stress 😀😀😀

Crop health / maturity 😀😀

Stressor identification 😀

Soil structure, 😀😀

chemistry, fertility 😀

moisture, 😀

microbiome 😟😟

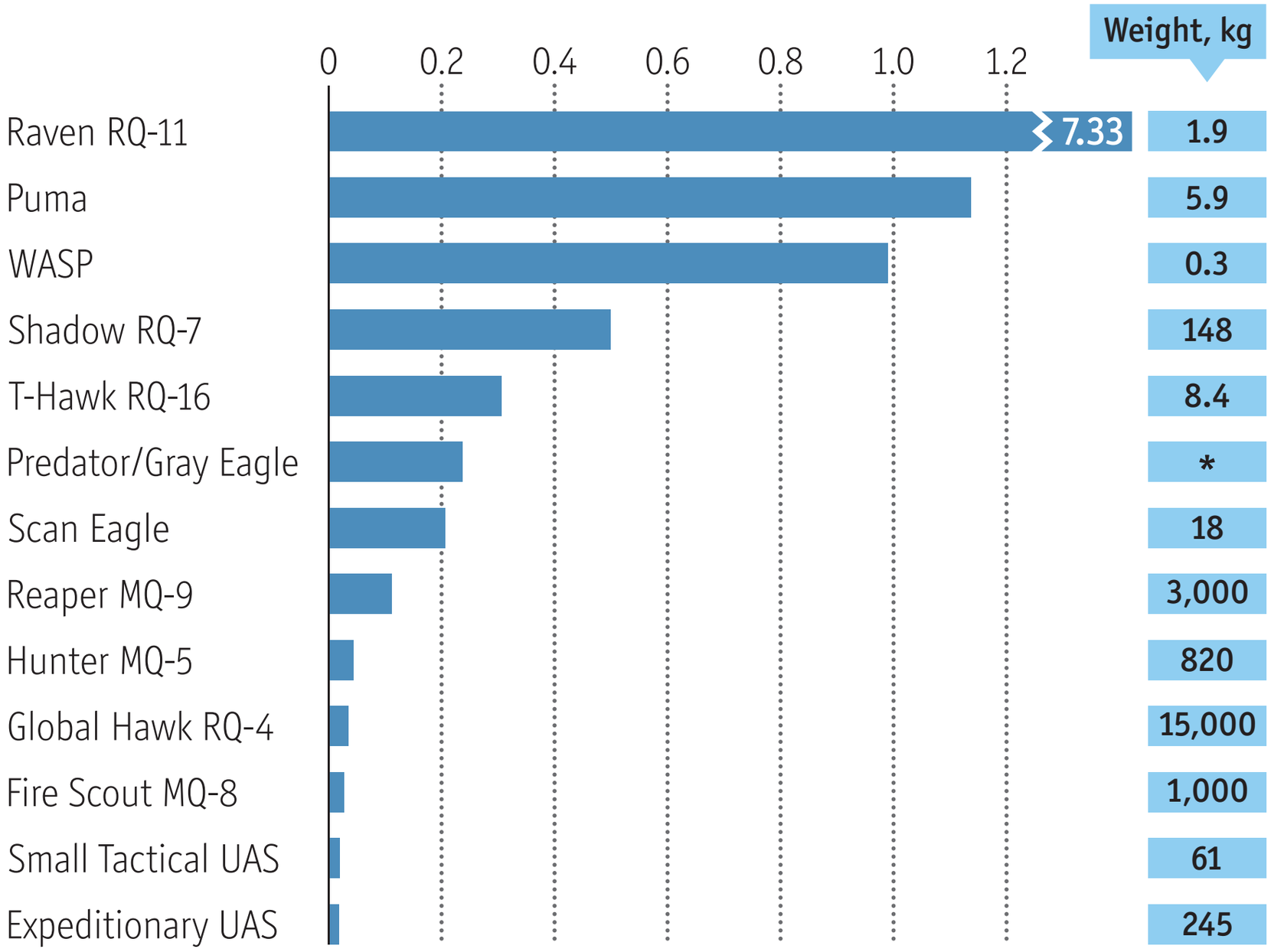
Food Quality Sensors

- Indicators of **external** quality (color, shine, shape, size, skin...)
- Indicators of **internal** quality (taste, texture, health...)
- Indicators of **spoilers** (residues, diseases, infections, infestations, age...)
- Heavy **throughput** systems for processing plants AND mobile systems for the supply chain and retail operations
- We cannot wait on ‘trickle down’ for other industries

UAV's

A menacing sky

American military unmanned aerial vehicles, 2013, '000



Source: US Department of Defence

*Predator=1,000kg, Gray Eagle=1,910kg

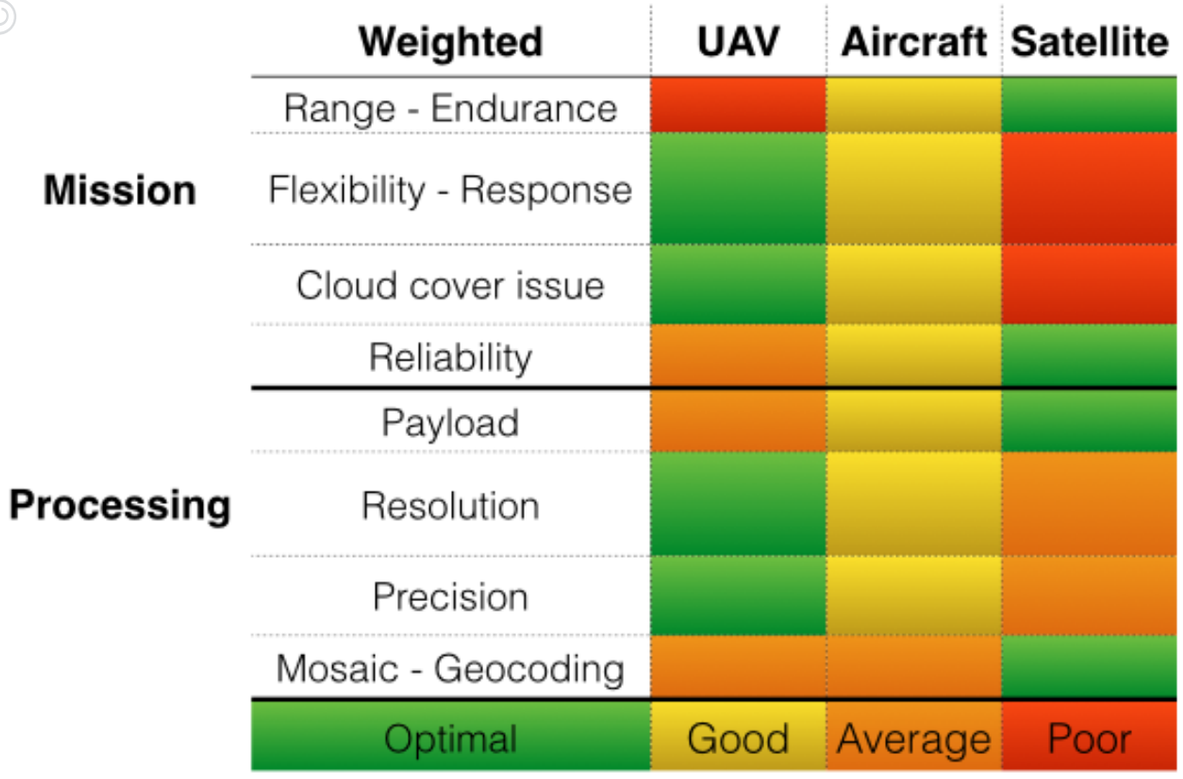
The Economist March 29th 2014

Different platforms

Inspired by: *Remote Sens.* **2015**, *7*, 2971-2990; doi:10.3390/rs70302971

	Weighted	UAV	Aircraft	Satellite
Mission	Range - Endurance			
	Flexibility - Response			
	Cloud cover issue			
	Reliability			
Processing	Payload			
	Resolution			
	Precision			
	Mosaic - Geocoding			
	Optimal	Good	Average	Poor

Compare platforms



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- UAV's are 'good' where it matters:
  - flexibility,
  - response time,
  - cloud cover issue,
  - resolution and precision
- UAV weaknesses will be resolved:
  - range & endurance
  - miniaturization of payload
  - better integrated into information / management cycles

Conclusion on UAV's

- UAV's today = remote sensing with passive sensors

—> LIGHT conditions remain a critical issue.

—> Acceptable to measure variability

—> Need ground truthing for absolute figures & prescriptions

Conclusion on UAV's

- Soon Operators will be excellent at 'flying'
- at the right time of the day
- in the correct direction for the issue to measure
- at the right height to optimize efficiency, resolution and precision

By 2025 UAV's will realize their full potential

- the next generation of sensors (new frequencies, active sensors, new NDVI models)

- meta data collection to improve post mission analysis

- algorythms to 'filter' and correct for the environment & timing in which they operate

- deployment justified by information / management cycles

Agricultural Equipment

Agricultura Equipment
Expect a few changes

Multi colored, multi pedigreed…
Hybrid & E Power
Power by Wire
‘Transformers’: entirely change a crop system

ALT-GREEN (HTTP://WWW.BBC.COM/AUTOS/COLUMNS/ALT-GREEN) | 6 March 2015

FarmDogg blends robotics with rutabagas

e-ATV

Ken Wysocky

Electric vehicles (http://www.bbc.com/autos/tags/electric-vehicles) Green (http://www.bbc.com/autos/tags/green) Motorcycles (http://www.bbc.com/autos/tags/motorcycles)

(Credit: Rogue Rovers)

In this feral age of Twitter and Instagram, sizzle trumps steak. Would you rather design work pants or create meat couture for Lady Gaga? Write a technical manual or author the next 50 Shades of Grey?

The small farmer's "e-mule"

- 660 Lbs
- no noise / fumes
- 4 E motors in the wheelhubs
- 180 miles / 6 hours range
- 31 mph
- no transmission (just D & R)

Kulan, Made in Germany at Fraunhofer Institute

E Motor = high torque

- Possible & potential new concepts:
    - Hybrid power (diesel + e)
    - Power by wire
        - Distributed power
        - Isobus 2.0 & 3.0
- Obsolete: transmissions, steering column, hydraulic brakes…
- If it works for nuclear submarines, airplanes, train locomotives, trucks, cars… it will work in agriculture.

“Transformers”: rice, SCAU

Mechanized transplanting

Precision seed bed + direct seeding

Precision seed bed + direct seeding + starter fertilizer

“Transformers”: Coffee, Brazil

Jacto K3500 machine + 3 accessories = 3 functions

- 2015: harvester / yield monitor
- 2016: low drift sprayer
- > 2016 pruning

—> Very High ROI of Hi-tech, P.A. & power components

“Transformers”: Coffee, Brazil

Jacto K3500 machine + 3 accessories = 3 functions

- 2015: harvester / yield monitor
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- > 2016 pruning

—> Very High ROI of Hi-tech, P.A. & power components

The Internet Of Things = Telemetry on Steroids

- NOT a technical issue (Military have had this working a while ago.)
- Business case may be difficult - because of lack of imagination?
- May come close:
    - Integrated hi-tech greenhouses
    - Integrated wheat harvesting in Hokkaido (JPN)
- Integrated fresh vegetables supply chains next ?
- By 2035 … it will be a normal part of any supply chain.

Wireless Networks

- Track & trace, surveillance and quality control
    - ‘in the field’ -
    - ‘in the plant’ -
    - ‘throughout the supply chain’
- First application: Telemetry for operational reliability
- ‘Nomadic’ systems that move with cropping seasons

Controlled Environment Ag

- Breakthroughs in the areas of energy - quality - automation - robotization - fertility - disease management - control

- Yields/acre 30-50 times open air cropping

- Integrate production - processing - supply chain - retail.

- Multiple layers and vertical

Controlled Environment Ag

- Breakthroughs in the areas of energy - quality - automation - robotization - fertility - disease management - control

- Yields/acre 30-50 times open air cropping

- Integrate production - processing - supply chain - retail (Maybe we can learn from pot in CO 😀.)

- Multiple layers and vertical

Big Data

System Integration

Let’s build a system…

- Libraries based
    - Software menus
    - Services list (i.e. each equipment & function is a service)
    - Registered weed / pest disease control products
    - Fertilizer formulations
    - Micro nutrient formulations

Let's build a system…

- Easy & intuitive (map navigation, GIS data) access to:
  - Soil maps
  - Field boundaries
  - Hydrology
  - Digital Elevation Maps
  - Weather: archives, ongoing, predictions

Let's build a system…

- Integrate / map / plot local **agronomy** data:
    - Remote images (satelite, airplane, drone…)
    - Soil sampling data and on-the-go soil measurements
    - Soil Fertility maps: base, prescription, as-applied
    - Crop Nitrogen maps (NDVI: remote, machine based, backpack)
    - Maps of aerial applications: prescription and as-applied
    - Weed, pest & disease maps: scouting, prescription & as-applied
    - Sensor networks for real time monitoring of crops
    - Yield maps

Let's build a system…

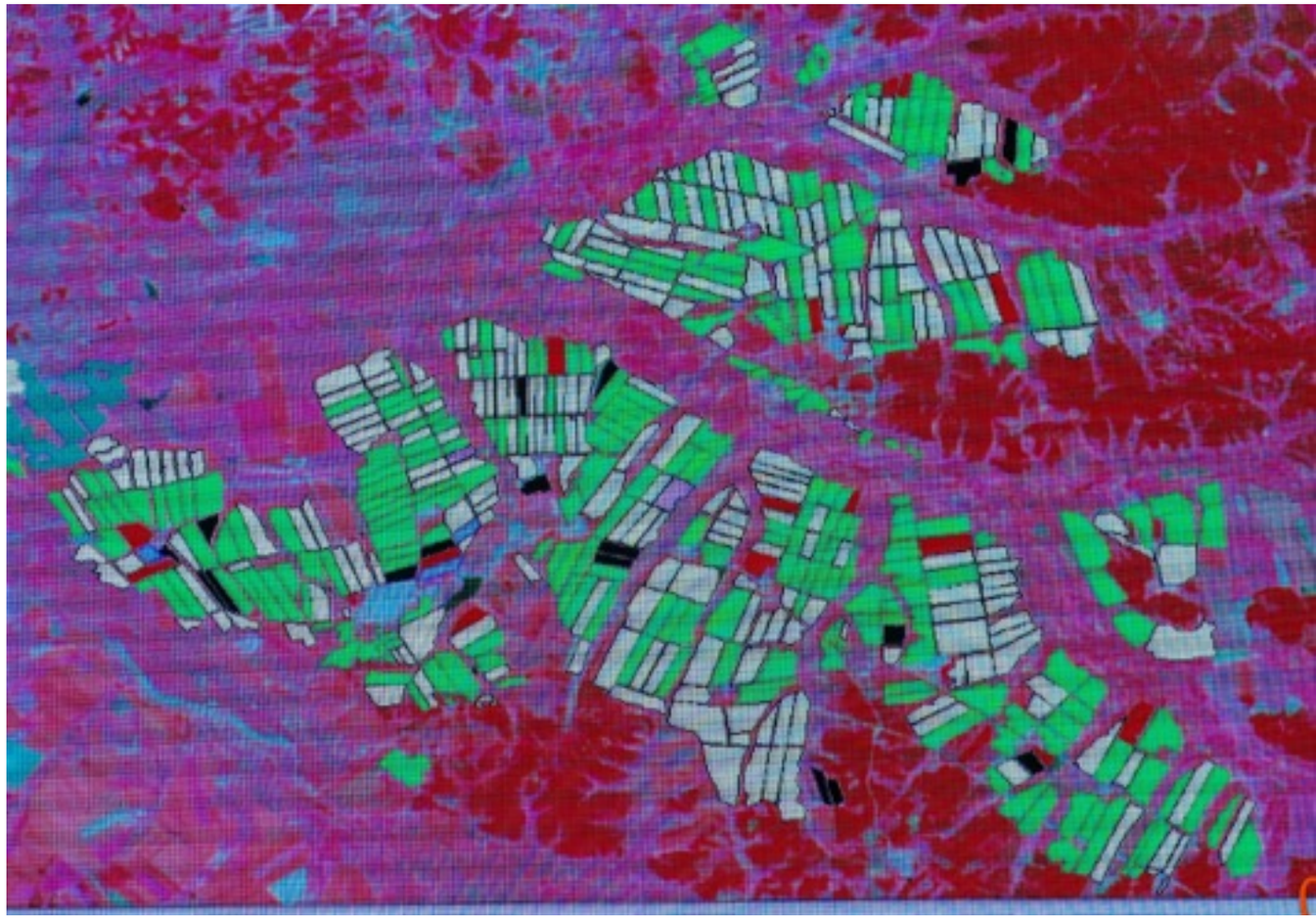
- Management:
    - Multimedia connection (including video) to each piece of field equipment
    - Equipment telemetry: operating status & location (RTK + laser)
    - Real time, cloud ready, but also off-cloud capabilities
    - Central 'control room' and tablet based

Let’s build a system…

- Industrial strength / scalable database (Oracle)
- Industrial strength / scalable GIS (ESRI)
- Multiplatform programnming language: Java
- Data access control: functional, geographic hierarchies
- < 1 second response lag time for standard queries

What if it exists today?

- Developed over 5 years (since 2009)
- At some point in time involved 180 developers
- Operationally & field tested on 75,000 acre (2 years)
- To be ‘Field Hardened’ on 800,000 acre in 2015-16
- Crops: corn, soy, rice, milo, organic vegetables



Who? What? Where?

NERCITA (National Engineering Research Center for Information Technology in Agriculture), Beijing, China

- Tested: Hong Xing (Red Star) State Farm

- Rolled out in 2015 in Heilongjiang Province, Bei'An District
- Presented to a panel of international experts in Sept 2014, at the occasion of CIGR 2015 (Worldwide version of ASABE)

A few additional questions:

When will we see…?

- Enclosed plant factories
    - Exist today. Issue of business model, not technology
- Nano scale weed & pest control
    - NO, weeds & pest are bigger than ‘nano’ (Gotcha 😏)
    - MAYBE nano scale disease control
- Intelligent templates for crop management
    - YES, they will be local, dynamic, adaptable and include statistical process control

Remember…

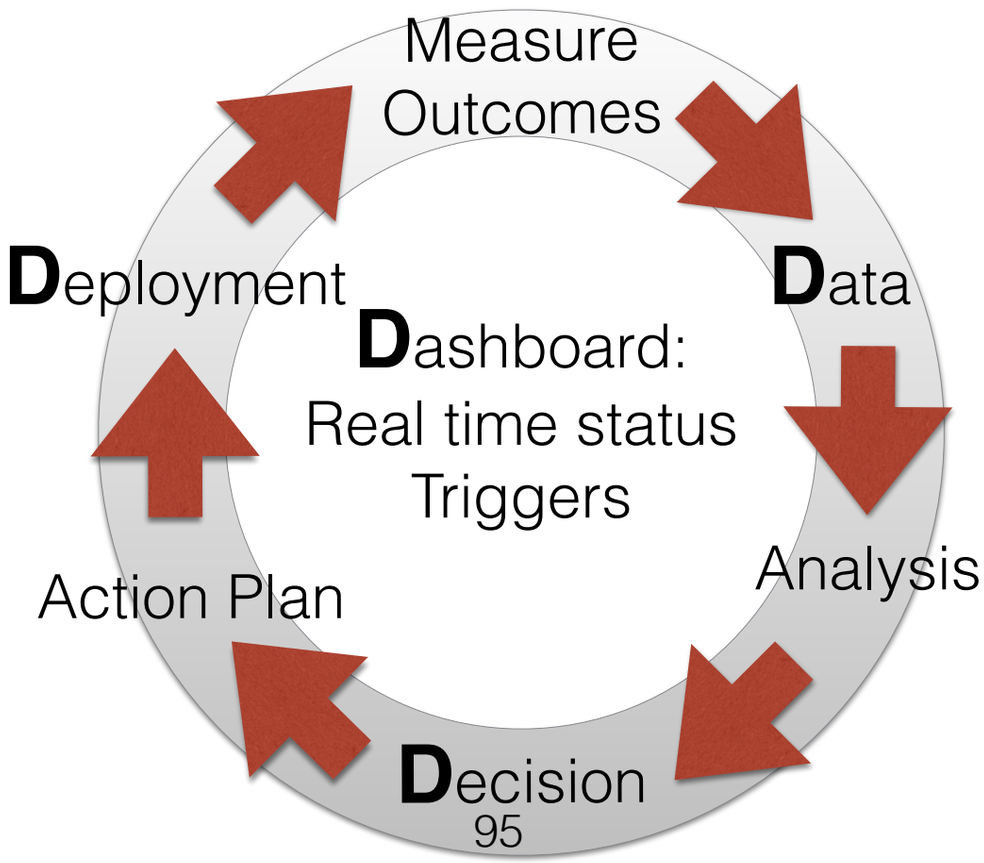
The Future is Now

Measuring & Data Tools

Visual-NRI-Multispectral-Fluorescence
Real time soil measurements
Tools for human scouts
Soil Sampler Robots
Digital Insect Traps
Sensor Platforms
Sensor Networks

Deployment Tools

Autosteer
V.R. Seeding
V.R. Sprayers
V.R. Irrigation
V.R. Spreaders
Telematics (Eqt.)
In-crop treatments
Telematics (Agronomy)
Autonomous Grain Cart



Analysis & Decision Tools

Weather data
Product libraries
Digital Soil Maps
Wireless networks
N dynamics models
Crop growth models
Field Boundary Data
Cloud based Services
Satellite Images Analysis

Thank You

C U in 2035 😀