講者簡介

Dr. Stavros George Vougioukas (USA)
Associate Professor,
Department of Biological and Agricultural Engineering,
University of California, Davis

Dr. Stavros George Vougioukas 擔任生物自動化實驗室（Bio-Automation Lab）的主任，負責特色作物機械化和自動化領域的相關研究，其中又以農用機器人和收成為重點。研究主題包括（但不限於）: 新型機器人和大規模收成系統水果採收機；採收過程中的人類─機器人互動；農業機械於田間的交通動線與物流工作；運用感測器自動導航的農用車輛等。

Dr. Stavros George Vougioukas as Director of the Bio-Automation Lab, I conduct research in the areas of mechanization and automation for specialty crops, with a strong focus on agricultural robotics, and harvesting. Research topics include, but are not restricted to: Novel robotic and mass harvesting systems fruit harvesters; Human-robot interaction during harvesting; In-field traffic and logistics for agricultural machines; Sensor-based autonomous navigation for agricultural vehicles.

QUALIFICATIONS

- Ph.D. Rensselaer Polytechnic Institute, Troy, NY, USA; Department of Electrical, Computers and Systems Engineering; August 1995.
- M.Sc. State University of New York at Buffalo, NY, USA; Department of Electrical and Computer Engineering; May 1991.

PROFESSIONAL EXPERIENCE

- 2016 - Today Associate Professor, University of California, Davis, Biological & Agricultural Engineering Davis
- 2012 – 2015 Assistant Professor, University of California, Davis, Biological & Agricultural Engineering Dept.
- 2011 – 2011 Visiting Associate Professor, University of Aarhus, Denmark, Biosystems Engineering Dept.

Bi Automatio Lab

Departmer of Biological & Agricultural Engineering
University of California Davis, CA 95616

Sponsors

Robotics for Smart Agriculture: State-of-the-art and Future Directions

Stavros G. Vougioukas

Associate Professor

Director Bio-Automation Lab

100 YEARS 1915 - 2015 UCDAVIS BIOLOGICAL AND AGRICULTURAL ENGINEERING

2019 International Conference on Smart Agriculture and Food Safety Management, Taiwan, R.O.C

Increasing press coverage for Agricultural Robots

THE WALL STREET JOURNAL.

Home World U.S. Politics Economy Business Tech Markets Opinion

Robots Head for the Fields

Forbes Billionaires Innovation Leadership Money Consume

How Big Data And Tech Will Improve Agriculture, From Farm To Table

The New York Times

As Immigrant Farmworkers Become More Scarce, Robots Replace Humans

PBS NEWS HOUR

What this apple-picking robot means for the future of farm workers

Why?

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智慧農業機器人：當前最佳狀態和未來方向

Stavros G. Vougioukas

副教授

生物自動化實驗室主任

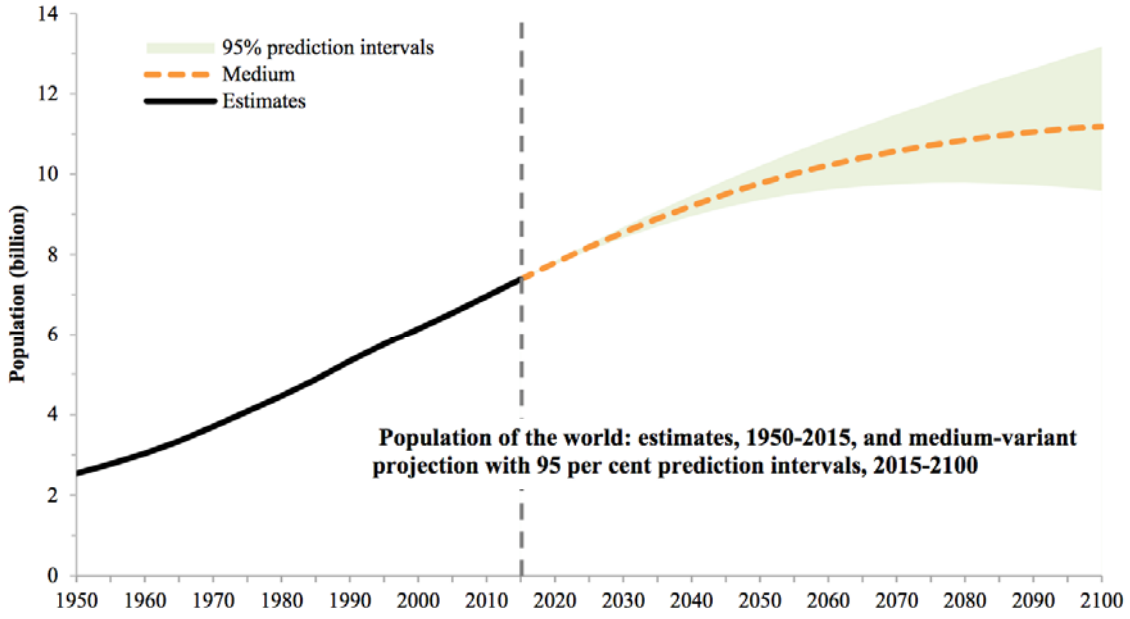
100 YEARS 1915 - 2015 UCDAVIS BIOLOGICAL AND AGRICULTURAL ENGINEERING

2019年台灣智慧農業和食品安全管理國際研討會

對農業機器人的報導增加

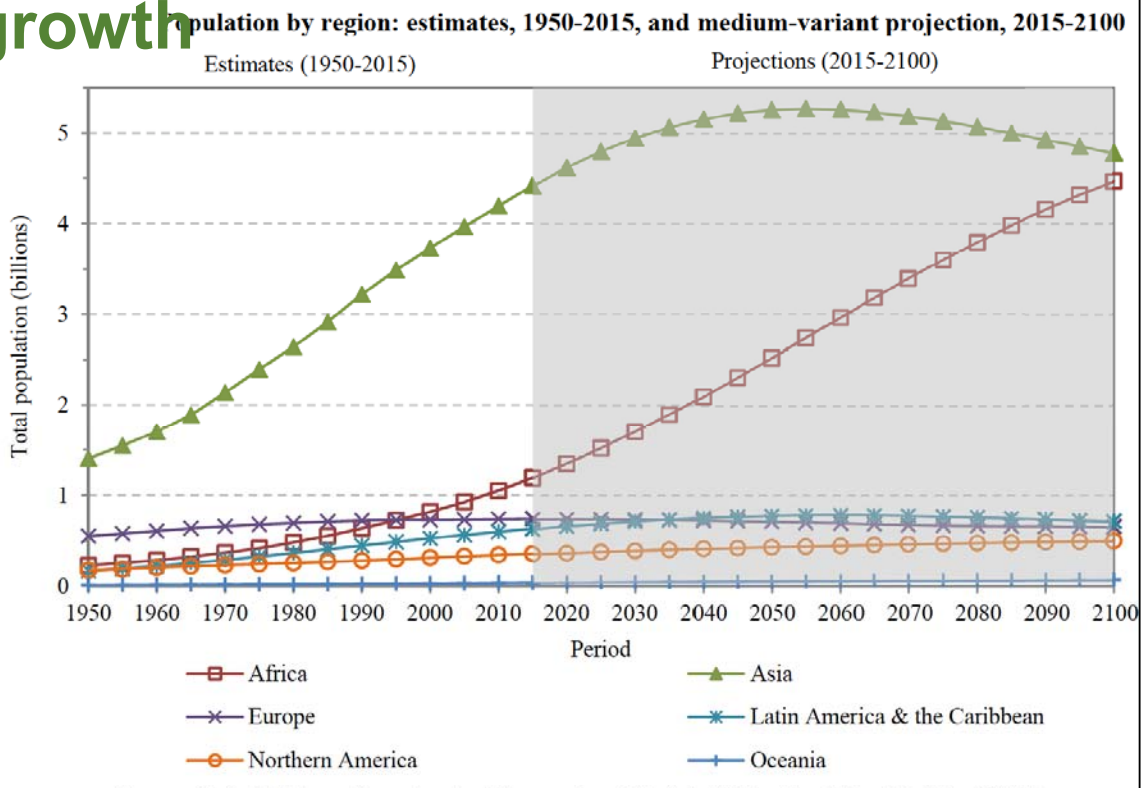
為什麼？

Trend: Population growth



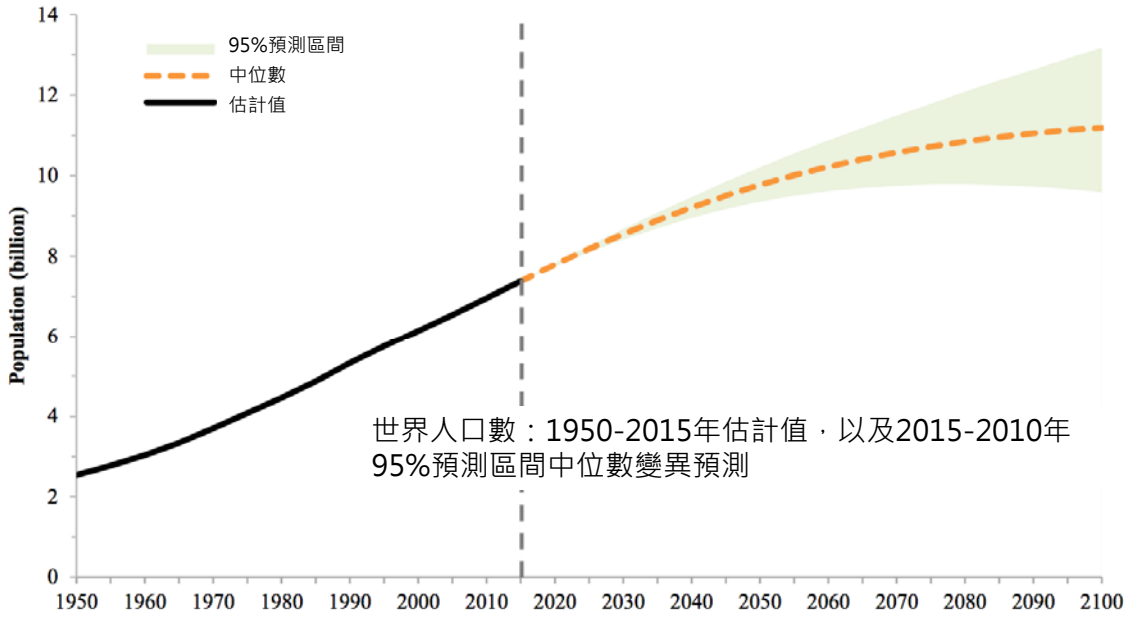
Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

Population growth per region



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

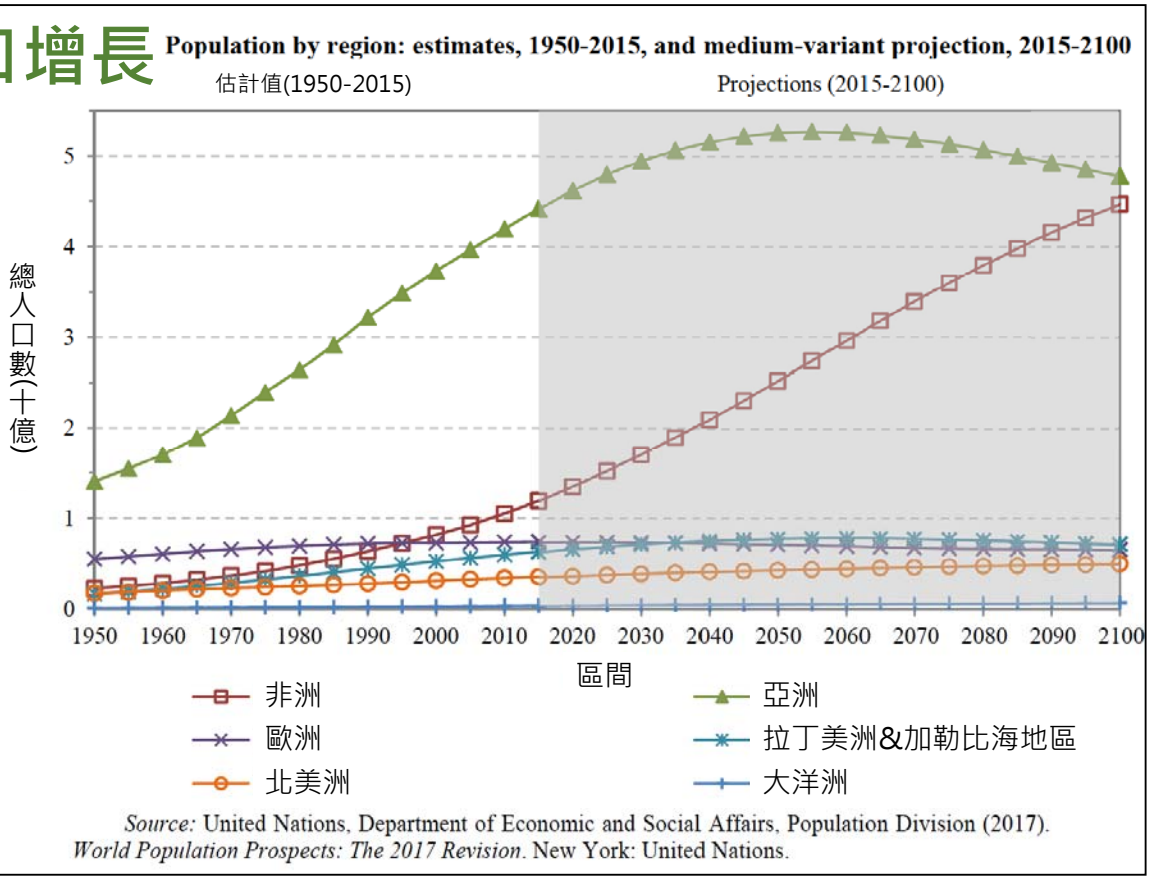
趨勢：人口增長



世界人口數：1950-2015年估計值，以及2015-2010年95%預測區間中位數變異預測

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

不同地區人口增長



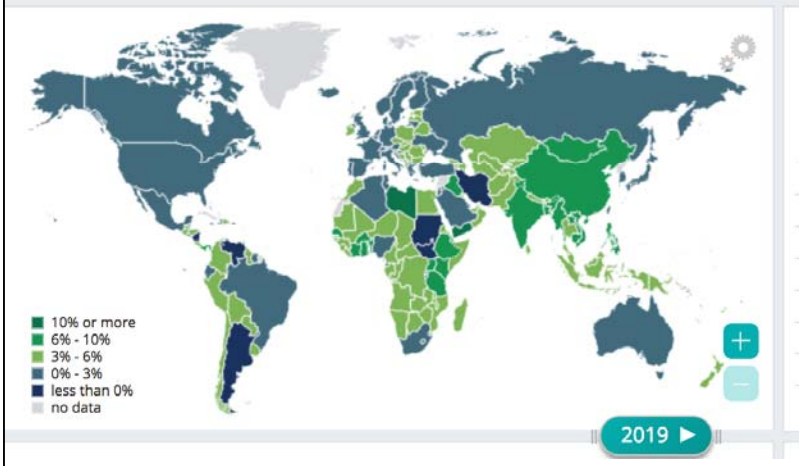
Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

IMF DataMapper

Real GDP growth

Annual percent change

INTERNATIONAL MONETARY FUND



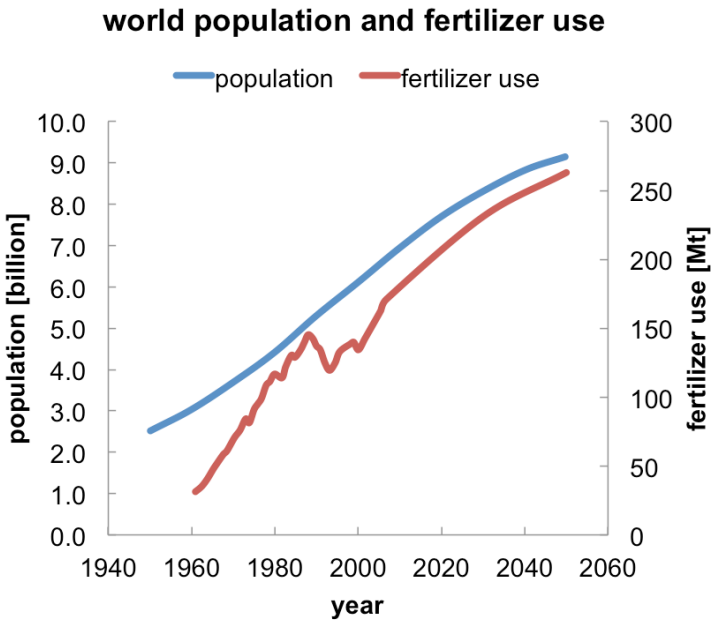
Datasets > World Economic Outlook (October 2018)

country | region | analytical group

region	value
South Asia	7
Asia and Pacific	5.2
Southeast Asia	5.1
East Asia	5
North Africa	4.5
Africa (Region)	3.9
Central America	3.8
Pacific Islands	3.7
Caribbean	3.7
Sub-Saharan Africa (Region)	3.5
Australia and New Zealand	2.8
North America	2.5
Eastern Europe	2.5
Western Hemisphere (Region)	2.4
Europe	2
South America	1.9

Trend: GDP growth

Trend: Increasing environmental impact

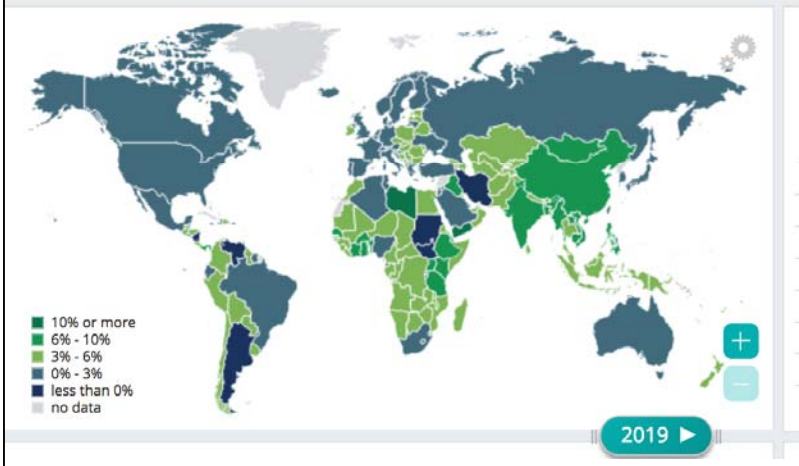


IMF DataMapper

Real GDP growth

Annual percent change

INTERNATIONAL MONETARY FUND



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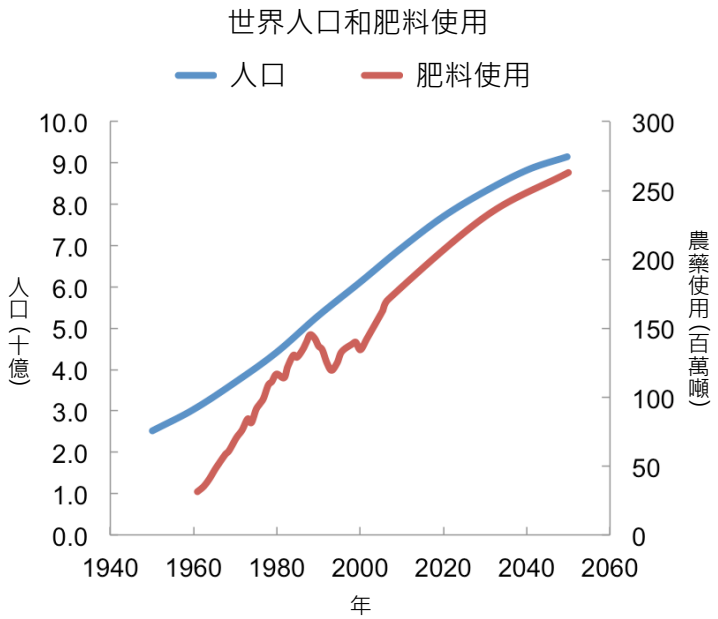
Datasets > World Economic Outlook (October 2018)

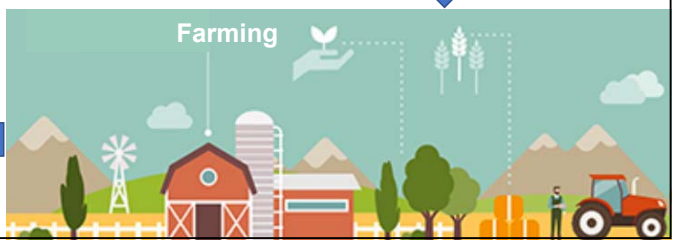
趨勢：國內生產毛額（GDP）成長

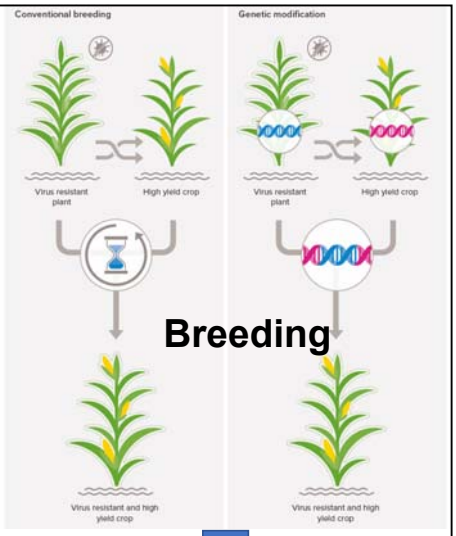
趨勢：環境影響增加



AGRI-FOOD Chain

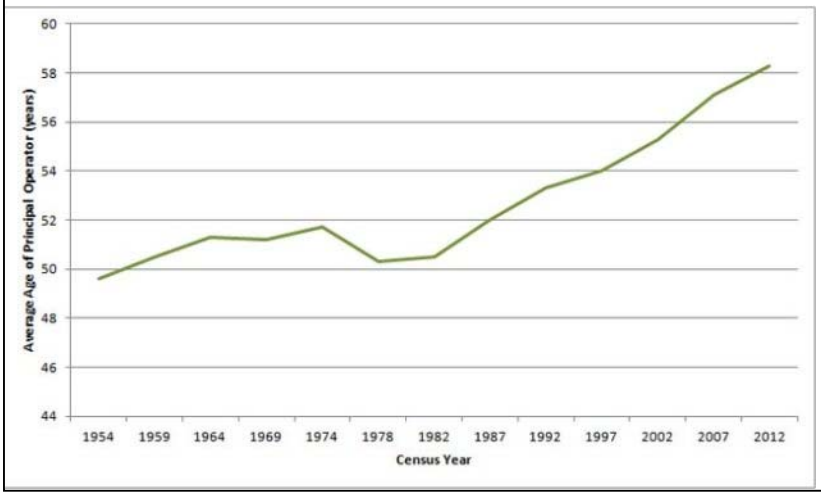
Challenge #1: Increase sustainably the supply of food, feed, fuel & fiber.





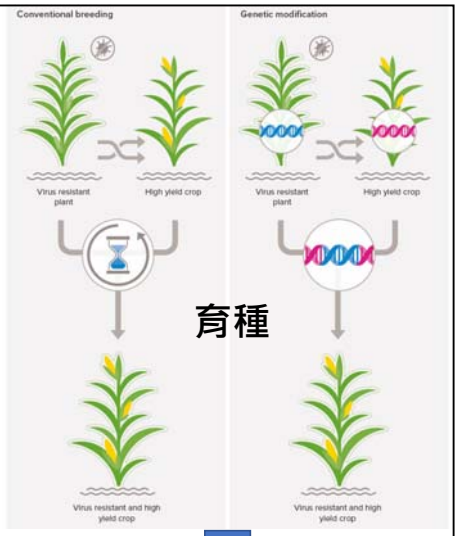
Trends: Aging farmer population and farm labor shortage

Average age of U.S. farmers



農業食品鏈

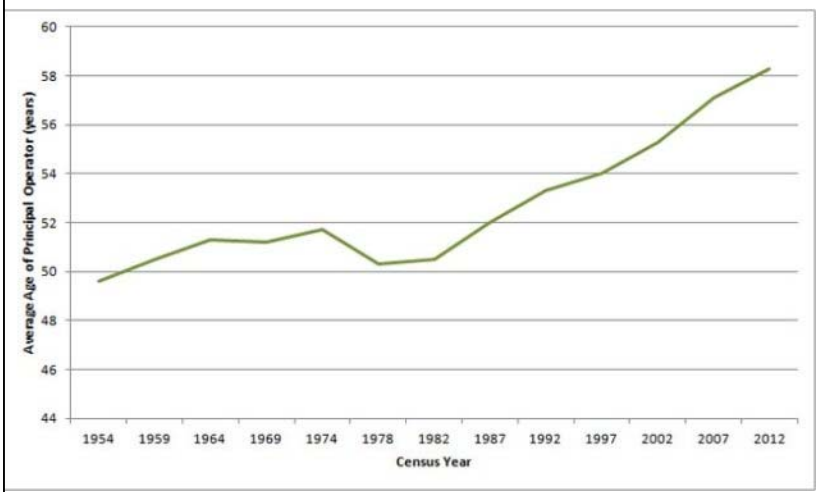
挑戰＃1：永續增加食物、飼料、燃料和纖維的供應。



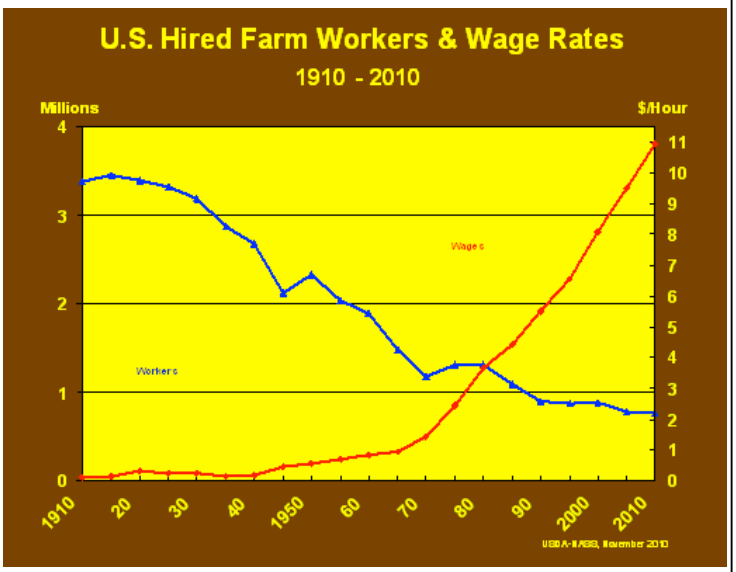
育種

趨勢：農民人口高齡化和農業勞動力短缺

美國農民平均年齡

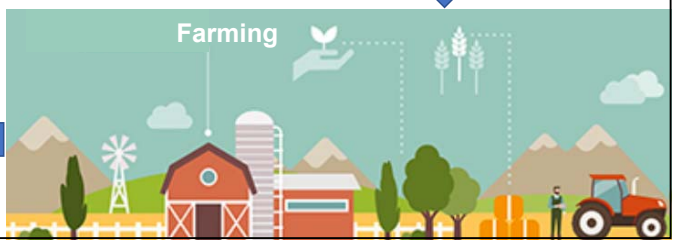


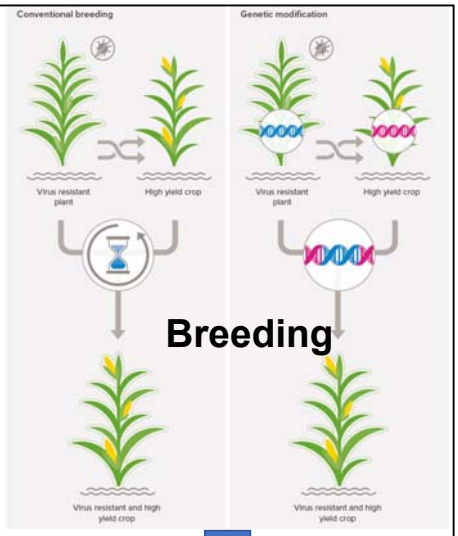
美國農場受雇勞動者和工資



AGRI-FOOD Chain

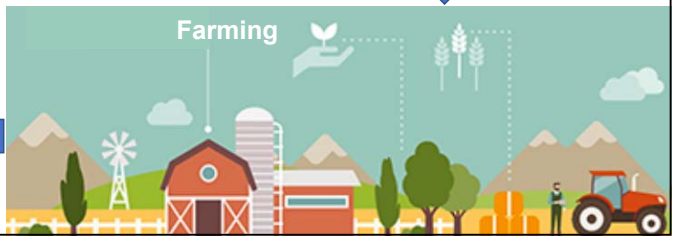
Challenge #2: Address farm labor shortages.

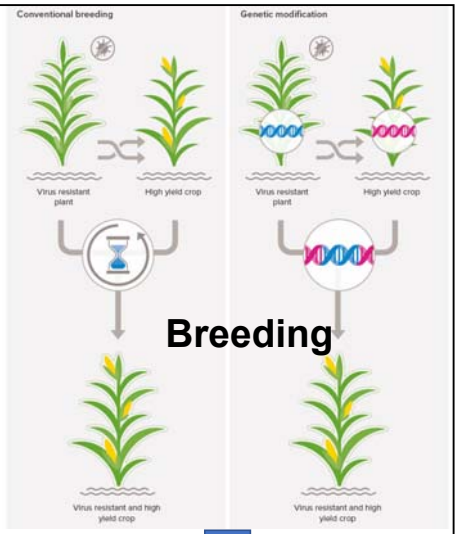




"Smart Agriculture"

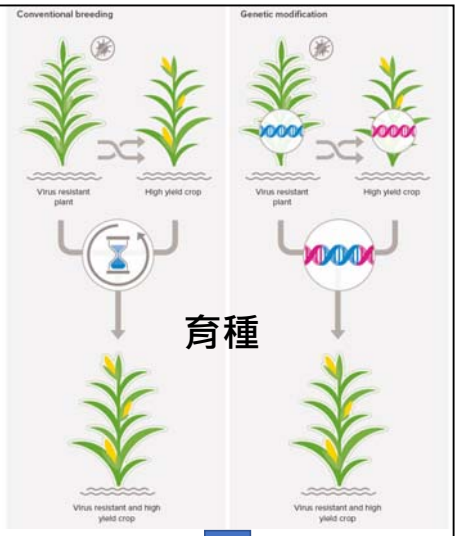
The use of technology (e.g., robots, sensors, data, algorithms, cloud) to increase the output & efficiency of the agri-food chain.





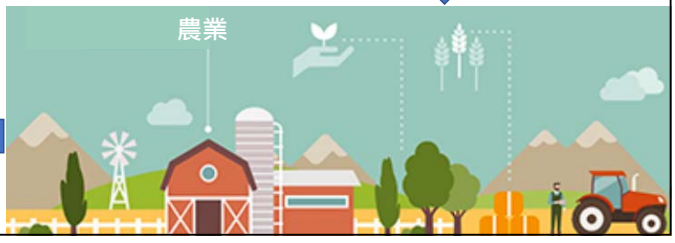
農業食品鏈

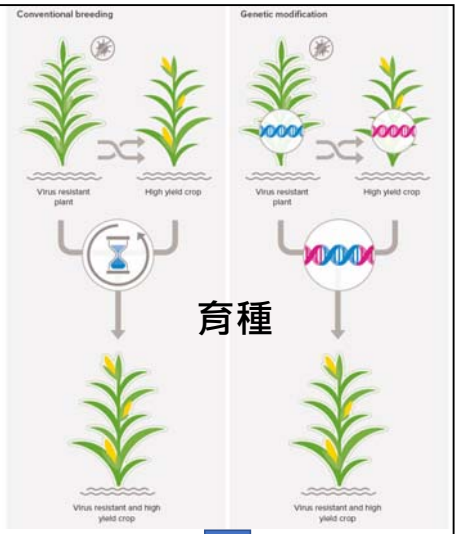
挑戰＃2：
解決農業勞動力短缺問題。



「智慧農業」

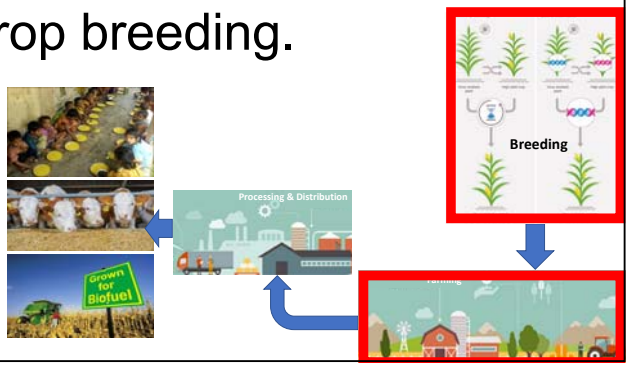
使用技術（例如：機器人、感應器、數據、演算法、雲端）來提高農業食品鏈的產量和效率。





Agricultural robotic technologies

- They offer automated sensing and actuation services.
- Intended primarily for implementing:
  - ➢Precision agriculture for crop production.
  - ➢Labor savings for crop production.
  - ➢High-throughput phenotyping for crop breeding.
- Applications in livestock and fish farming are not covered today.

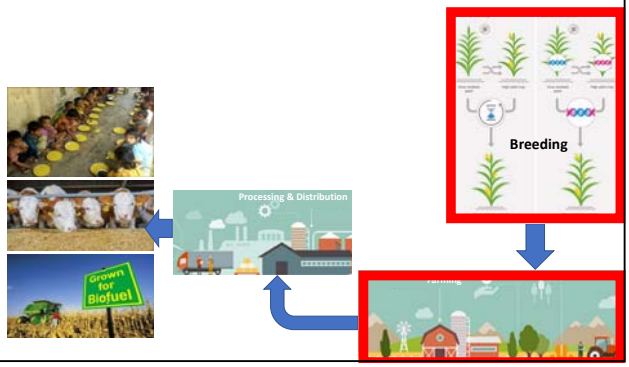


Agricultural robot types for crops

- Flying vehicles.
- Self-propelled ground vehicles.
- Smart implements.

農業機器人技術

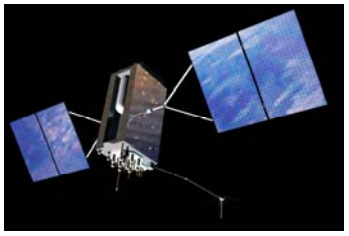
- 提供自動感應和驅動服務。
- 主要用於：
  - ➢精準農業。
  - ➢節省作物生產所需的勞動力。
  - ➢用於作物育種的高通量表型分析。
- 不包含在家畜和漁業養殖中的應用



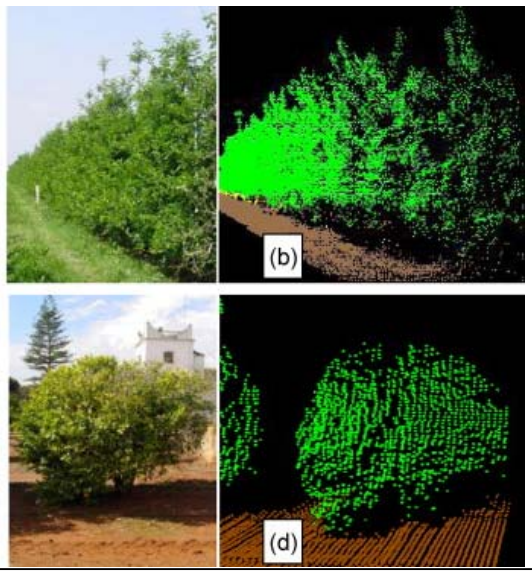
農業機器人種類

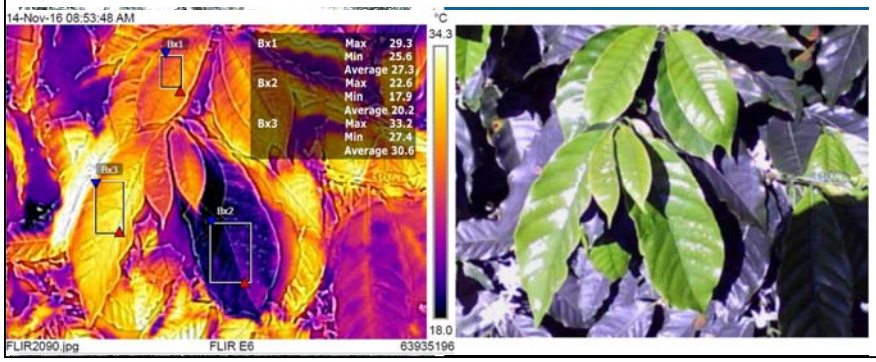
- 飛行器
- 自動式地面車輛
- 智慧工具

Agricultural robots - Sensors



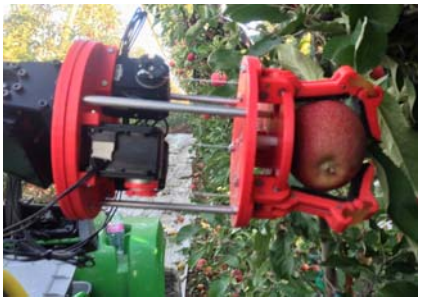
- Robots use *sensors* to gather data; e.g.:
  - GNSS.
  - LIDAR.
  - 2D and 3D Cameras.
  - Thermal & multispectral imaging.



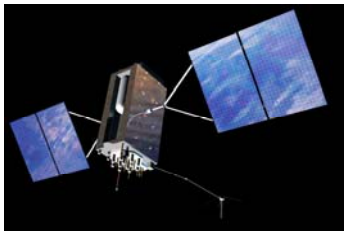


Agricultural robots - Actuators

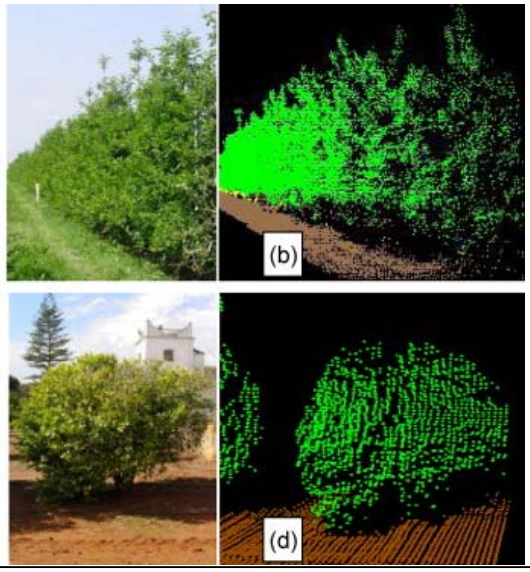
- Robots use *actuators* to interact with crops and their environment.
- Mass delivery
  - Spray, fertilize.
- Mass removal
  - Prune, sample, harvest.
- Energy delivery
  - Heat, press, vacuum.

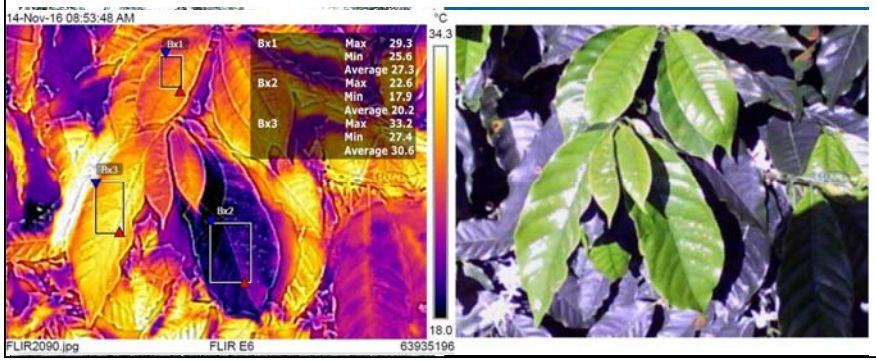


農業機器人 - 感應器



- 機器人使用感應器收集數據，例如：
  - 全球導航衛星系統（GNSS）
  - 光學雷達（Lidar）
  - 2D和3D相機。
  - 熱影像和多光譜影像。





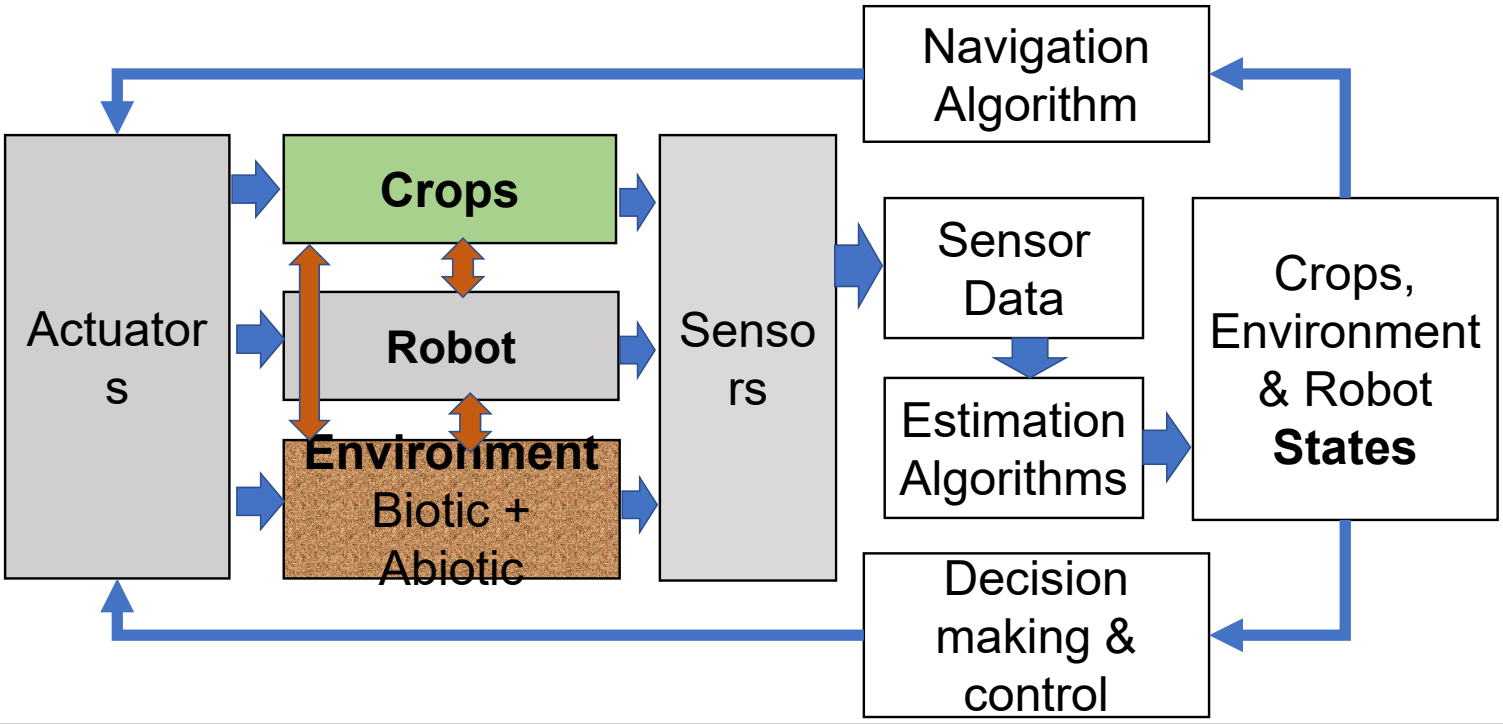
農業機器人 – 趨動器

- 機器人使用趨動器與作物及其環境互動。
- 大量投遞
  - 噴灑、施肥。
- 大量移除
  - 修剪、採樣、收成。
- 能量輸送
  - 加熱、按壓、真空。

Agricultural robots - Algorithms

- Use real-time *algorithms* to:
  - ➢Move/operate autonomously, safely and reliably (navigation).
  - ➢Extract task-relevant information from sensor data (estimation).
  - ➢Compute appropriate actions (decision making & control).

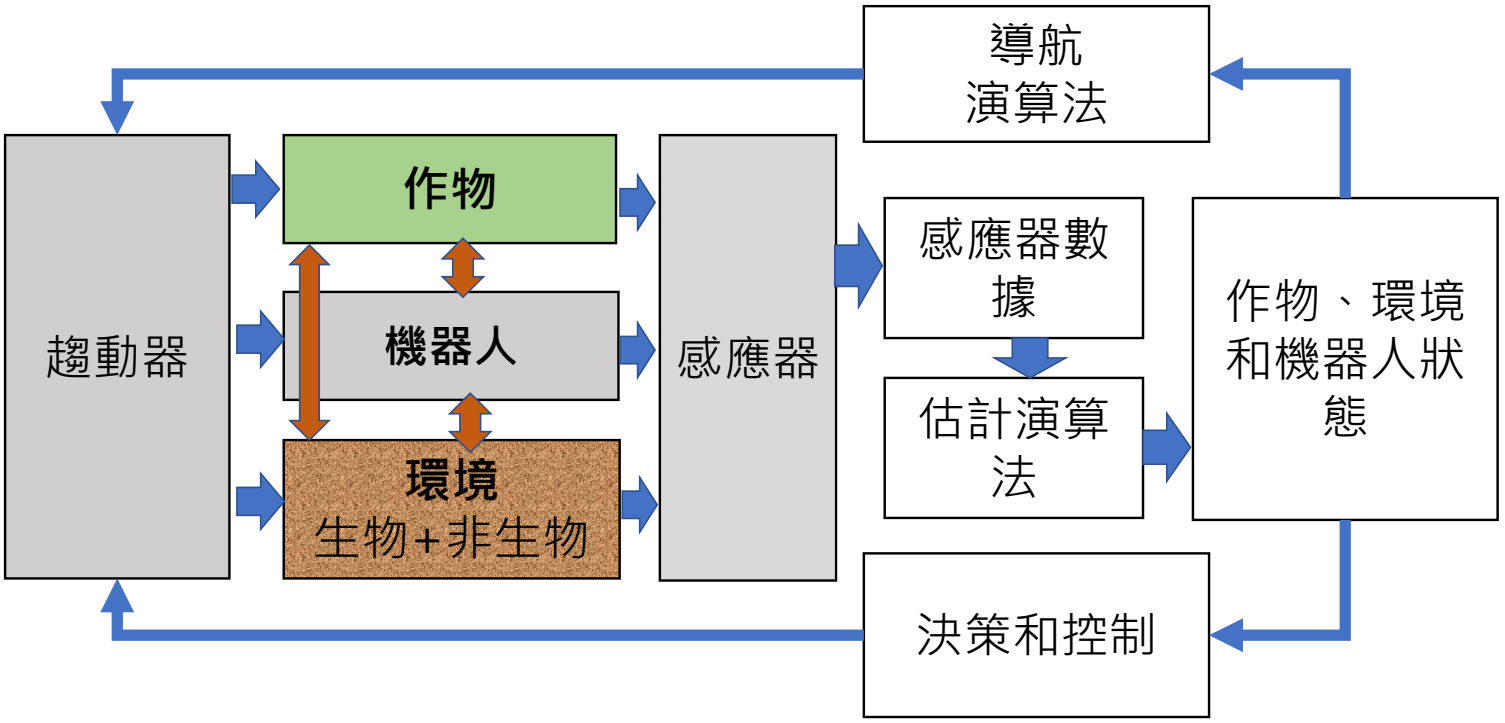
Agricultural robot operations



農業機器人 - 演算法

- 使用即時演算法：
  - ➢安全可靠地自動移動/操作（導航）。
  - ➢感應器數據提取任務相關訊息（估算）。
  - ➢計算適當的行動（決策和控制）。

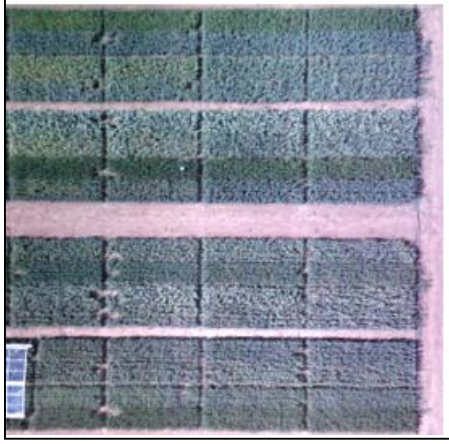
農業機器人操作

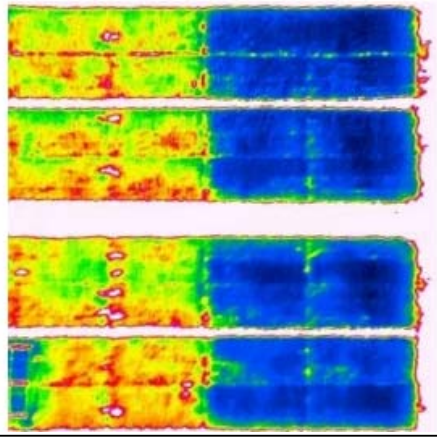


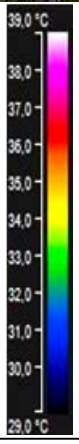
Categories of Ag robot operations

- Sense-only; no actuation upon crops or environment.
  - ➢Crop scouting and phenotyping.

Sense-only: Crop imaging - scouting



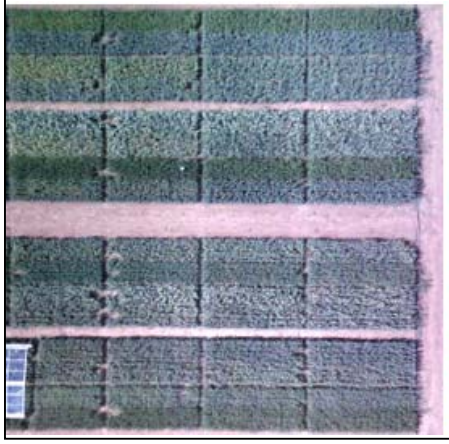


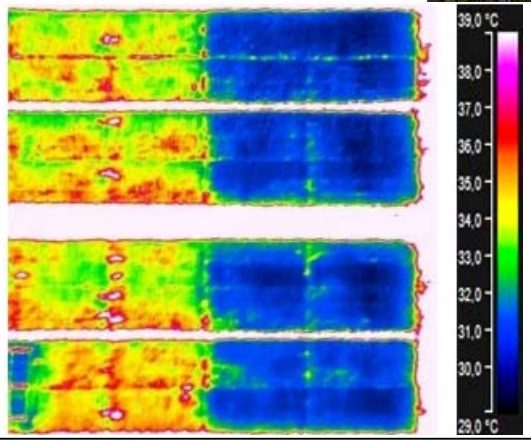


農業機器人操作類別

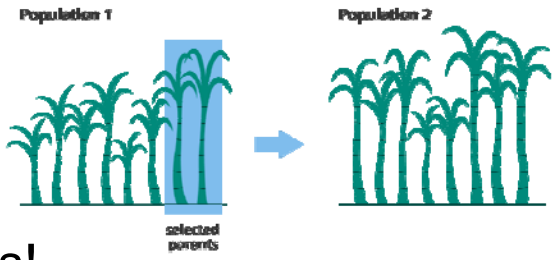
- 感應型：對作物或環境沒有驅動作用。
  - ➢作物偵察和表型分析。

感應型：
作物成像 - 偵察

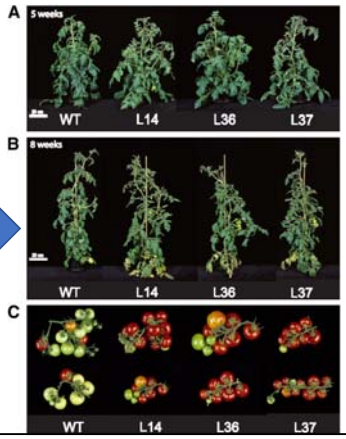


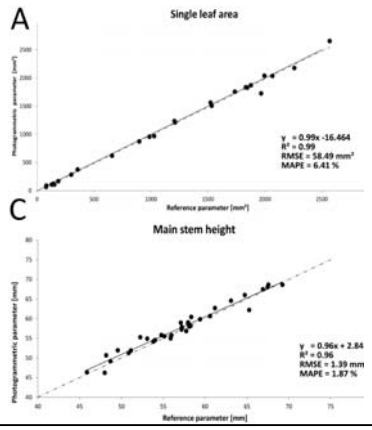


Sense-only: Phenotyping



- Breed productive and resilient plants.
- A numbers ‘game’: try more combinations!
- Data collection and analysis are expensive & slow.





Sense-only: Phenotyping

- Robots can automate field data collection.

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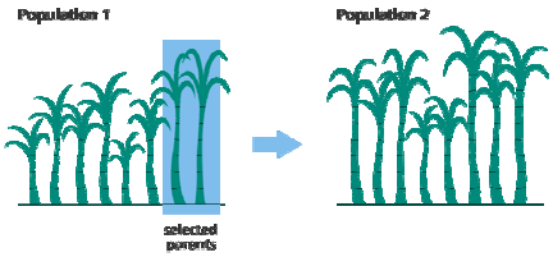
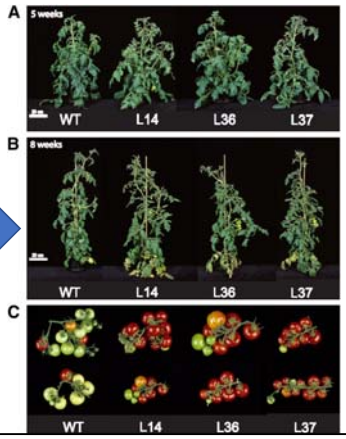
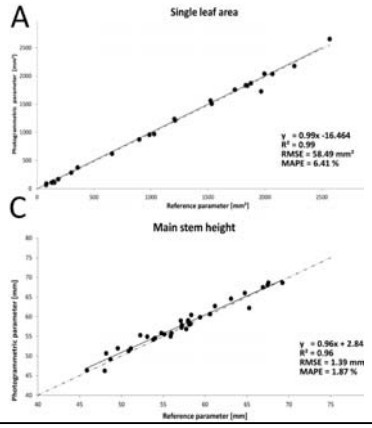
感應型：表型分析



- 培育有生產力和適應力強的植物。
- 數字「遊戲」：嘗試更多組合！
- 數據收集和分析既昂貴又緩慢。





感應型：表型分析

- 機器人可以自動化田間數據收集。

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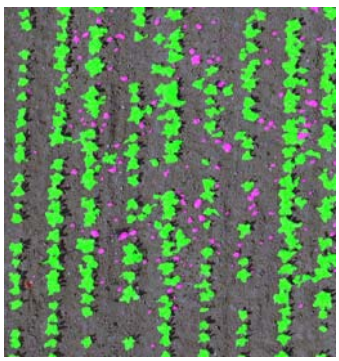
Categories of Ag robot operations

- Sense-only.
  - Crop scouting and phenotyping.
- Sense only, and later, act selectively
  - Prescription-based precision farming.

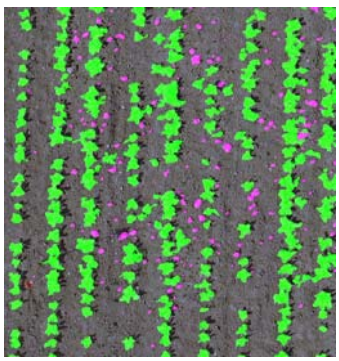
Sense; later, act selectively



農業機器人操作類別

- 感應型：
  - ➢作物偵察和表型分析。
- 先感應，後選擇性行動
  - ➢基於指示的精準農業。

先感應，後選擇性行動

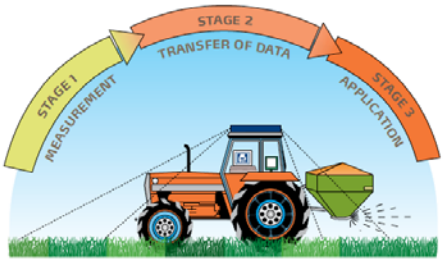


Categories of Ag robot operations

- Sense-only.
  - Crop scouting and phenotyping.
- Sense only, and later, act selectively
  - Prescription-based precision farming.
- Sense and act selectively, in real-time.
  - On-the-go precision farming.
  - Weeding, thinning.
  - Harvesting fruits and vegetables.

Sense and act selectively, in real-time

- On-the-go precision farming (Variable Rate Applications).

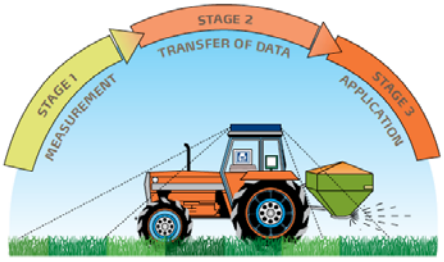


農業機器人操作類別

- 感應型：
  - 作物偵察和表型分析。
- 先感應，後選擇性行動
  - 基於指示的精準農業。
- 即時感測和選擇性行動
  - 即時反應的精準農業。
  - 除草、疏苗。
  - 採收水果和蔬菜。

即時感測和選擇性行動

- 即時反應的精準農業
  （可變速率應用）



Sense and act selectively, in real-time

- Thinning and weeding (commercial technologies).

Sense and act selectively, in real-time

- Harvesting fruits and vegetables (prototype stage technologies).

即時感測和選擇性行動

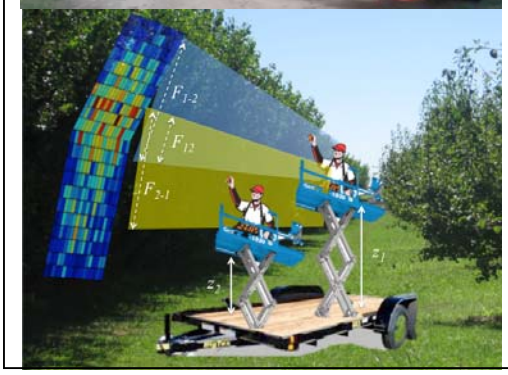
- 疏苗和除草
  （商業技術）

即時感測和選擇性行動

➢採收水果和蔬菜
（原型時期技術）。

Sense and act selectively, in real-time

- Human-robot collaboration.

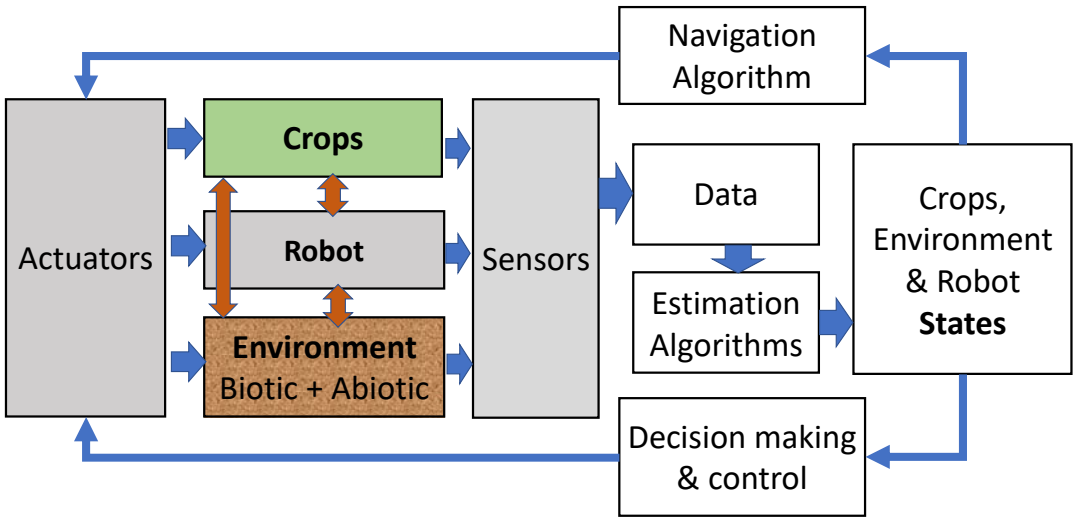


NRI: Robotic Harvest-Aiding Orchard Platforms

S. Vougioukas[1] (PI), G. Kantor[2], D. Slaughter[1], F. Fathallah[1]

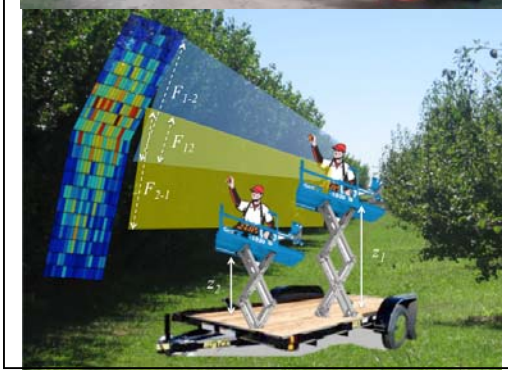
[1]University of California, Davis
[2]Carnegie Mellon University

Challenges for Ag Robot Operations



即時感測和選擇性行動

- 人機協作。



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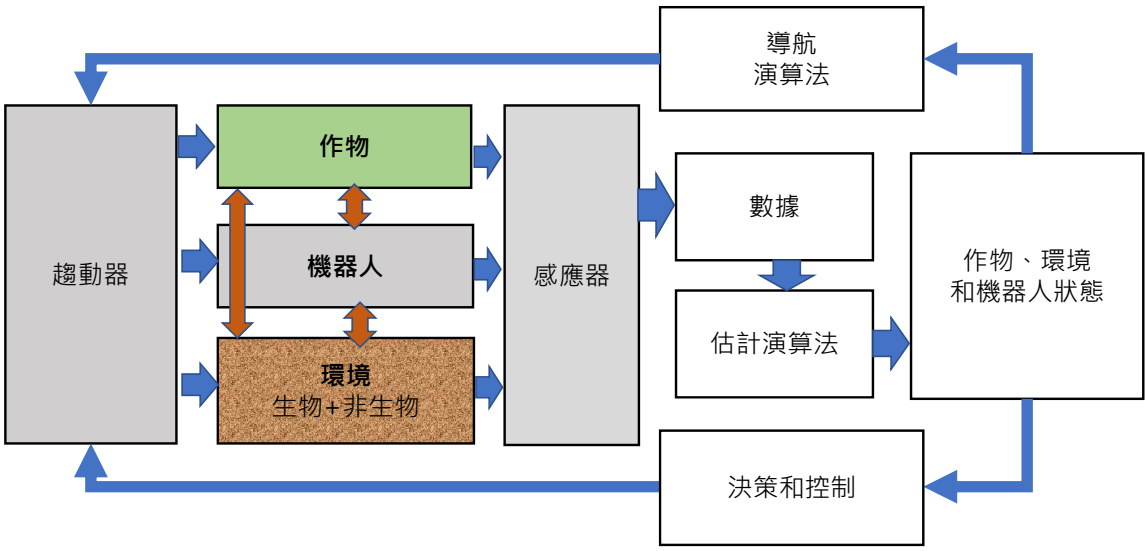
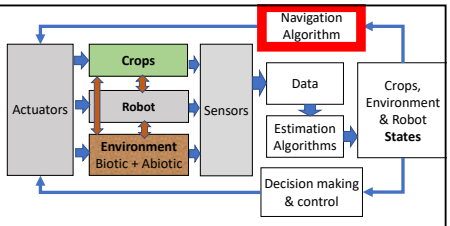
農業機器人操作所面臨的挑戰

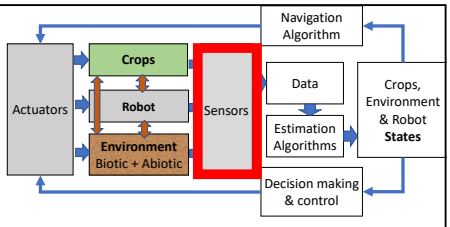


Navigation with unreliable GNSS



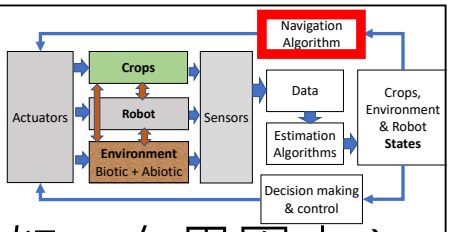
- **Goal**: Auto-guidance (e.g. in orchards), with accuracy, safety and reliability.
- **Challenges**:
  - ➢Biological, horticultural & environmental variability.
  - ➢Presence of people, animals, obstacles, and other machines.

Sensing



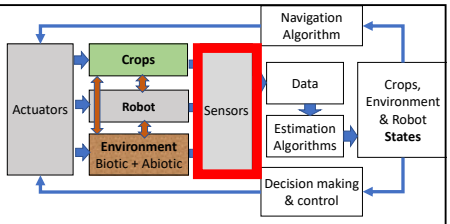
- **Goal**: Gather data relevant to crop and environment properties, at high throughput.
- **Challenges**:
  - ➢Dynamic, harsh environmental conditions;
  - ➢Complicated plant structures limit sensing (visibility);
  - ➢Large amounts of data (storage, transmission).

全球衛星導航系統的導航並不可靠



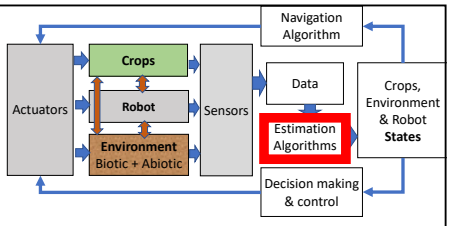
- 目標：準確、安全、可靠地自動導航（例如：在果園中）
- 挑戰：
  - ➢生物、園藝和環境變異。
  - ➢人、動物、障礙、和其他機器的存在。

感測



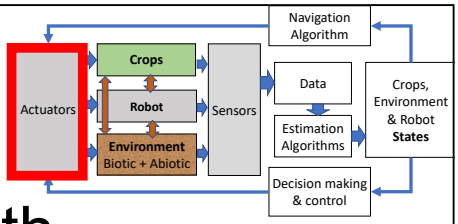
- 目標：在高通量下收集與作物、環境特性相關的數據。
- 挑戰：
  - ➢動態、惡劣的環境條件；
  - ➢複雜的植物結構限制了感測（能見度）；
  - ➢大量數據（存儲、傳輸）。

Estimation of crop & environment properties



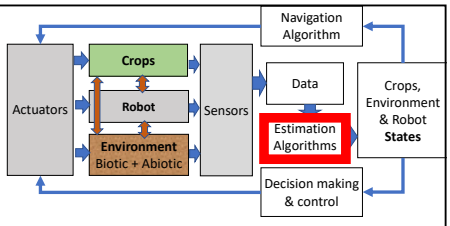
- **Goal**: Estimate crop and environment properties, from data, with *accuracy and precision*.
- **Challenges**:
  - Complexity and variability of plant responses.
  - Multiple causes can contribute toward a response.
  - Large amounts of data and compute power.

Actuation



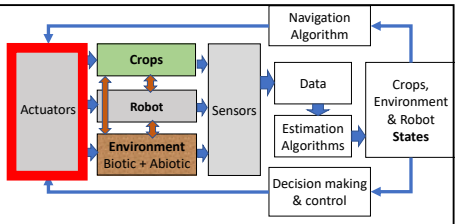
- **Goal**: Operate cost-effectively, with high speed and success rate.
- **Challenges**:
  - Plant tissues can be easily damaged.
  - Large variability in physical properties of the targeted plants or plant components.
  - Limited machine accessibility due to plant structure.

作物和環境特性估算



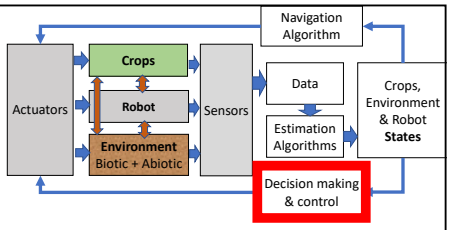
- 目標：根據數據，準確和精確地估算作物和環境特性。
- 挑戰：
  - ➢植物反應的複雜性和可變性。
  - ➢多種原因都會影響反應。
  - ➢大量數據和計算能力。

趨動



- 目標：以具成本效益的方式運營，高速和高成功率。
- 挑戰：
  - ➢植物組織很容易被破壞。
  - ➢目標植物或植物組成的物理性質變化大。
  - ➢由於植物結構，機器可達性有限。

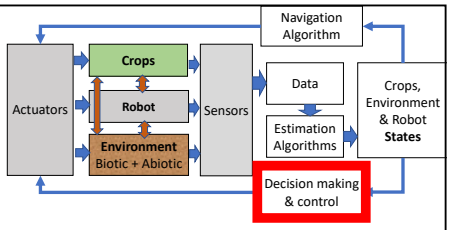
Decision making



- **Goal**: Map crop and environment properties into *management actions* that optimize cultivation objectives.
- **Challenges**:
  - Complexity and uncertainty in interactions of crop Genetics, Environment and crop Management (G×E×M).

Possible Future Directions

決策



- 目標：將作物和環境特性納入優化栽培目標的管理行動中。
- 挑戰：
  - 作物遺傳（G）、環境（E）和作物管理（M）相互作用的複雜性和不確定性（G×E×M）。

未來可能的方向

Teams of smaller robots

- The current trend:
- An alternative:

Teams of smaller robots

- Smaller robots may be affordable by small farmers too.

小型機器人團隊

- 目前趨勢：
- 另一種選擇：

小型機器人團隊

- 小農可能也負擔得起較小的機器人

Systems approach for robotic crop production

Engineering + Biology + Horticulture



- Co-develop plants (breed, train) and robots (design, program) to improve sensing and actuation.
- Introduce low-cost infrastructure to increase safety and reliability of robot operations.

Data sharing among Ag robots

- Robots collect and share data - via the cloud- from huge numbers of plants, at many different locations, under widely ranging environmental conditions and management strategies.
- Big data can be used to:
  - Calibrate models.
  - Train estimation algorithms.
  - Learn G×E×M interactions.

用於機器人作物生產的系統方法

工程 +生物+ 園藝



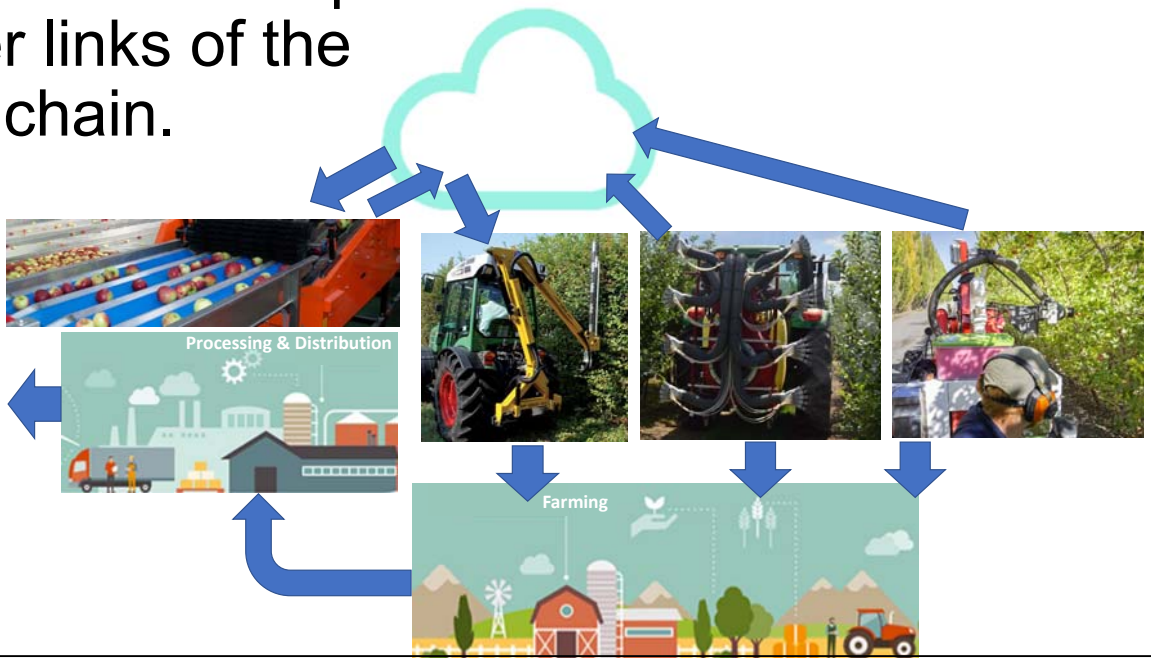
- 共同開發植物（育種、培育）和機器人（設計、程式）以改善感測和驅動。
- 引入低成本基礎設施，提高機器人操作的安全性和可靠性。

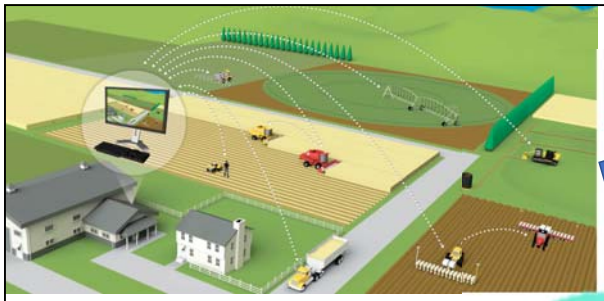
農業機器人之間的數據共享

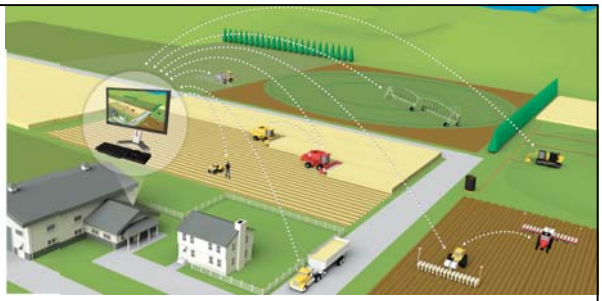
- 在廣泛的環境條件和管理策略下，機器人透過雲端，從位於許多不同地點的大量植物收集和共享數據。
- 大數據可用於：
  - ➢校正模型
  - ➢訓練估計演算法
  - ➢學習G×E×M互動

New data paths in the Agri-food chain

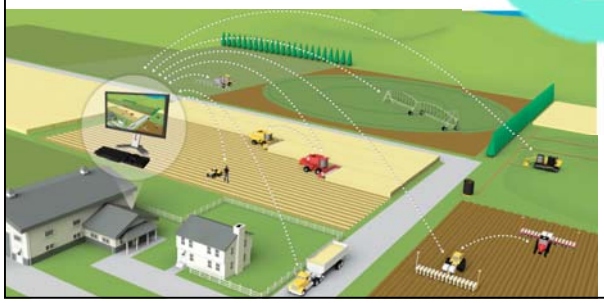
- Local decisions incorporate data from other links of the agri-food chain.

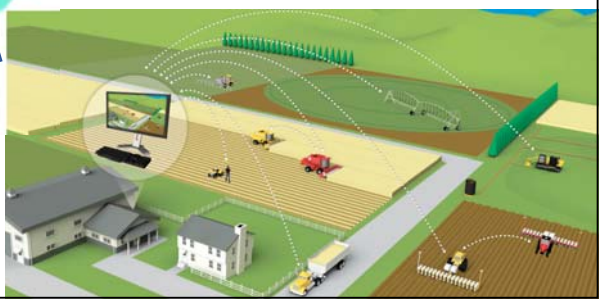






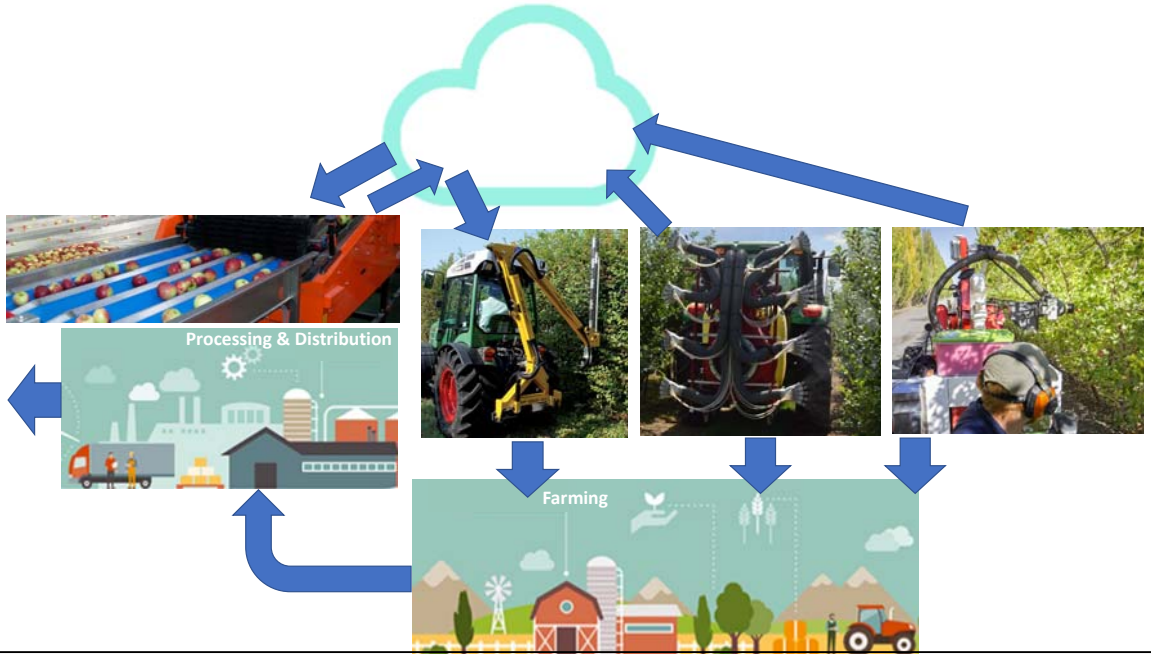
- Robots and sensors generate – and share large amounts of data, in fields and the post-harvest chain.
- Distributed software helps optimize the entire agri-food chain.
- Ag robots are the physical components of a **Cyber-physical system**.

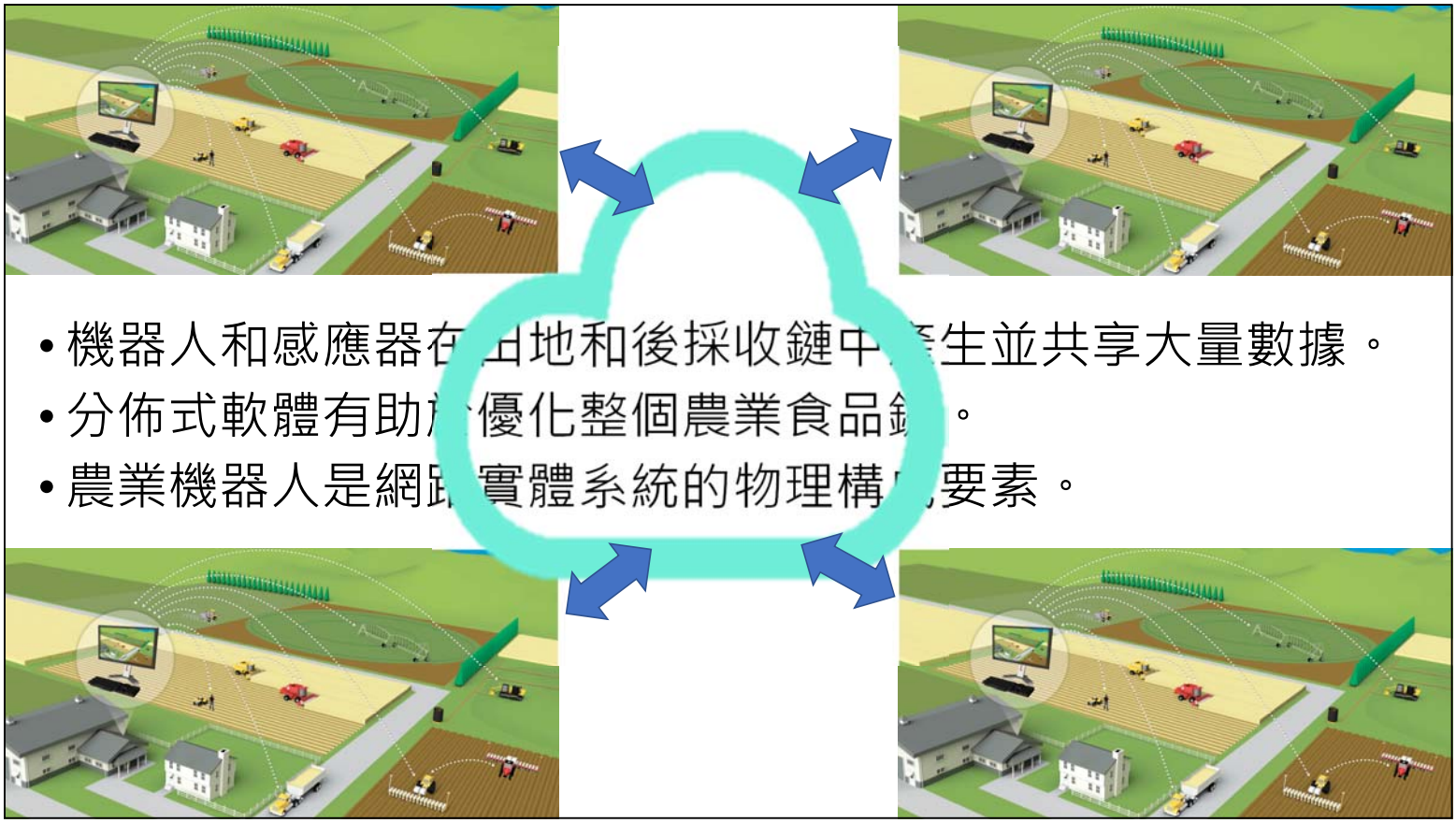




農業食品鏈中的新數據路徑

- 本地決策納入來自農業食物鏈中其他鏈結的數據





- 機器人和感應器在田地和後採收鏈中產生並共享大量數據。
- 分佈式軟體有助於優化整個農業食品鏈。
- 農業機器人是網路實體系統的物理構成要素。

Thank you!

Thank you!