PLANTS

RESEARCH ACADEMIC COMPUTER TECHNOLOGY INSTITUTE CTI

eden project

NMRC Ireland's ICT Research Institute

Information Society Technologies

Objectives

PLANTS: Enabling Mixed Societies of Communicating Plants and Artefacts

The goals of the project are to:

1. To study plant ecosystems in order to understand their sensing and communication mechanisms;
2. To use this understanding to create models for the specification of the plant-artefact interfacing mechanisms;
3. To design and develop sensors and sensor networks to be implanted around and on plants that will transform biological signals into digital signals;
4. To design and develop biosensor and actuator networks to provide artefacts with the ability to induce complex responses from plant-life and perceive their environment in a plant-like way;
5. To design and implement a specific middleware (ePlantOS) to support the establishment of networked interacting plant-artefact societies. This will allow an investigative study of selected plant-life and interaction with the environment (people included); and
6. To create two primary demonstrators, one focused on horticulture and the other combining mixed societies of humans, plants and artefacts.

Vision

PLANTS: Enabling Mixed Societies of Communicating Plants and Artefacts

The aim of this RTD project is to enable the development of synergistic and scalable mixed communities of communicating artefacts and plants.

This project proposes to develop complex interactive systems by embedding sensors on and around individual plants, and by developing middleware that will enable the integration of distributed systems composed of sensors and artefacts into ecosystems.

The project is seeking to merge hardware, software, and distributed wireless, modular systems to develop a comprehensive technology platform that provides interfaces to plants that ranging from macroscopic human interfaces down to microscopic levels.

The project aims to develop truly novel technology platforms by focusing on solutions for prototype system demonstrators feasible during the project lifetime, and commercially viable solutions within 5 to 10 years.

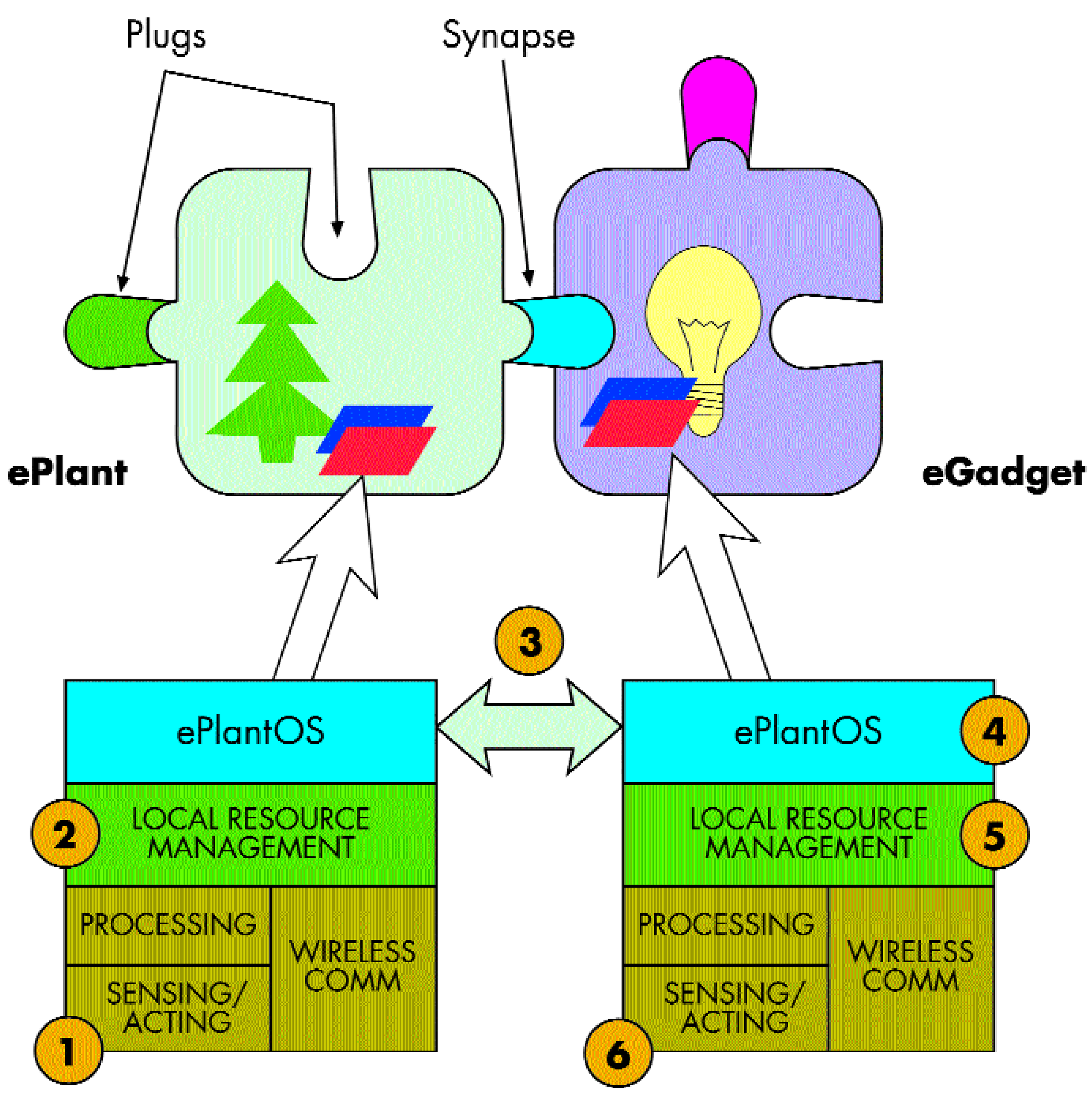
Scenarios

The mixed societies concept, as implemented in the PLANTS project, has a range of applications with varying degrees of impact, including:

- The environment where human activities take place (home, office, etc.)
- The space where public activities happen (open space, urban / city, etc.)
- The management of crops and infrastructure of plant production (for food, raw material, etc.)
- Optimisation of different factors that affect crops (use of pesticides, diffusion of signals, reaction time, etc.)

A scenario workshop was held on 26th - 28th August 2003 resulting in several scenario ideas; the PLANTS consortium shall implement selected scenarios from this set.

An example of ePlant / eGadget Interaction



Step 1:
The Biosensor/Bioactuator network transforms selected chemical signals into digital signals.

Step 2:
The ePlant Local Resource Management Unit reads the digital signals and translates them into a command passed to the ePlantOS.

Step 3:
The middleware (ePlantOS) selects the appropriate Plug and passes the information to the connected eGadget by using the Synapse channel.

Steps 4-6:
The eGadget middleware interprets the received information, acts upon an eGadget using it's Local Resource Management Unit, subsequently triggering the actuator through the sensor/actuator network.

Challenges

The challenges of the PLANTS project are:

- To define physical and chemical parameters in plants for translation into digital signals;
- To investigate volatile signalling in plants and utilise the results in developing sensor thresholds;
- To explore issues relating the nature of communication capabilities (‘Plugs’ in ePlants) and the enforcement of seamless plant/artefact interactions;
- To develop the PLANTS ontology;
- To integrate commercially available sensor devices into technology platforms which are highly miniaturised and packaged for appropriate deployment with reliable performance; and
- To disseminate the PLANTS project results to specialist and non-specialist audiences, conveying both the intricacies of the technology and the fundamental importance of new technology in the more sustainable management of resources in ecological systems e.g. agriculture.

Component Philosophy

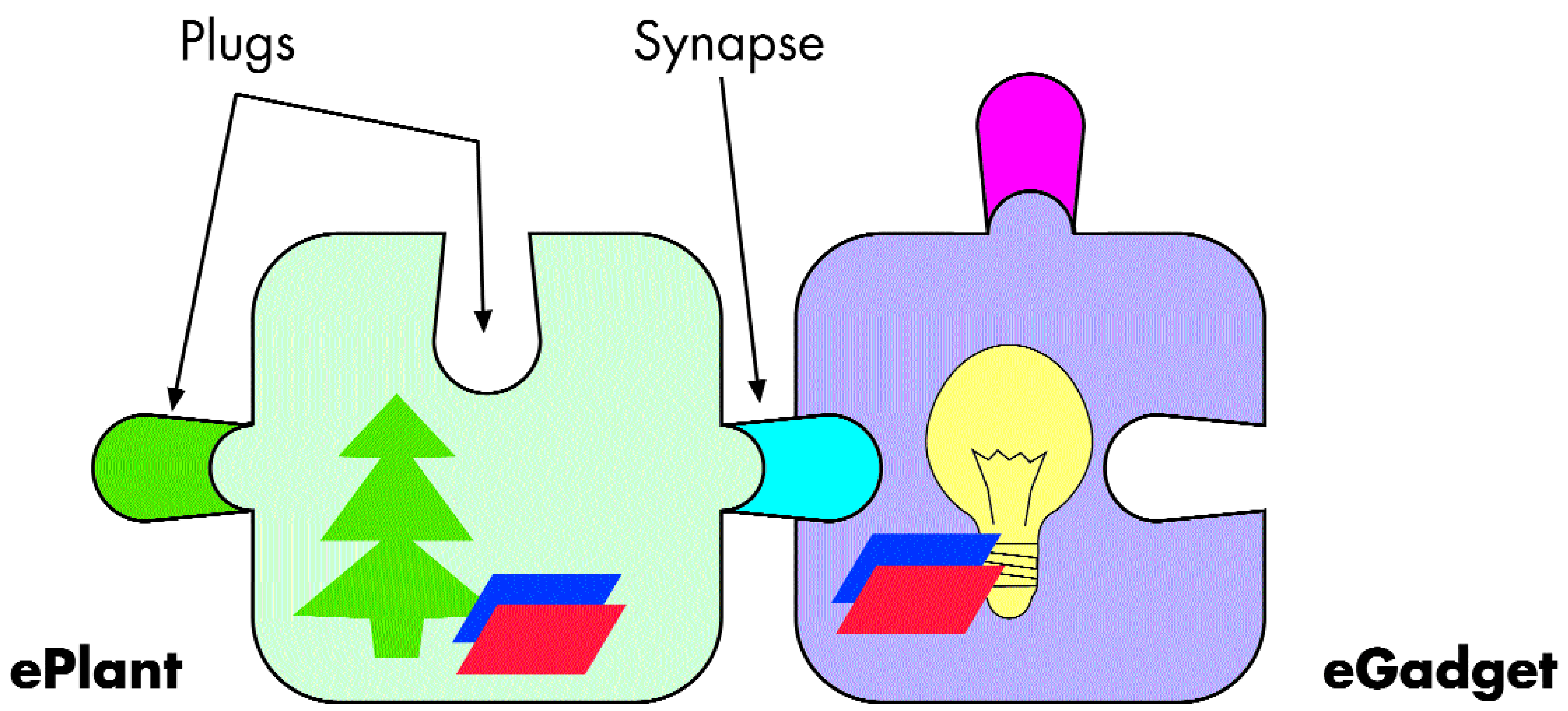
The jigsaw of everyday life

The inspiration

Contemporary software developers compose software systems of pre-fabricated, adaptable and replaceable software components, which have the ability to collaborate with other components through typed communication points called "plugs". Thus, they can create applications knowing only the connections each component provides.

The vision

Plants become components of ambient distributed systems by interacting with artefacts in their environment via wireless communication channels.



The technology

ePlantOS: the middleware software layer that manages local resources (sensors, actuators, processor, wireless communications), implements Plugs, provides persistence and connectivity services, supports service discovery and manages Synapses.

The tools

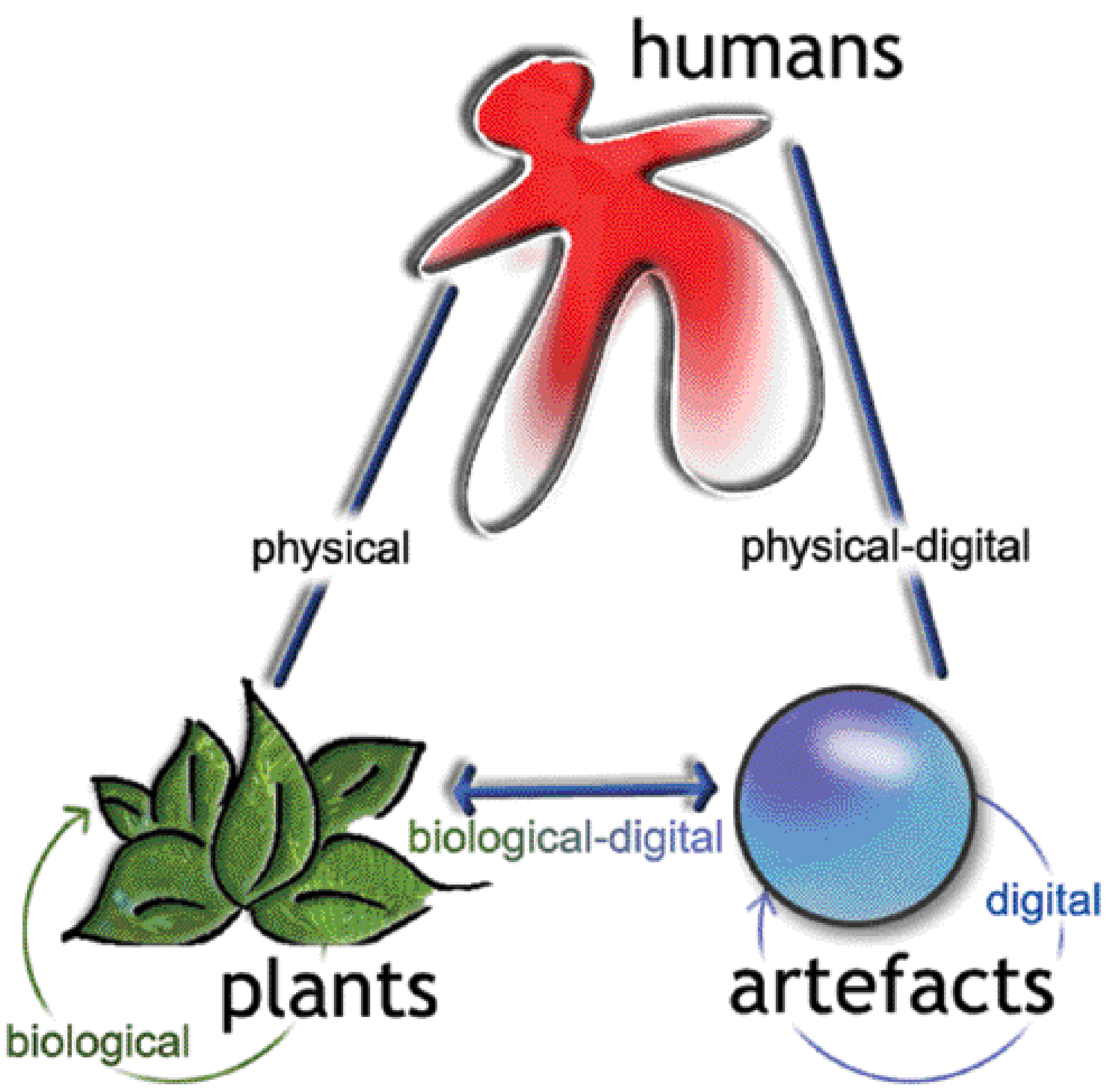
BioGW Editor: an application that supports the establishment and management of bioGadgetworlds in a user-friendly manner.

PLANTS Ontology: a tool that provides the common basis for the communication and collaboration among ePlants and eGadgets, by describing the semantics of the basic terms and defining the relations among them.

Mixed Societies

Plants are part of the natural environment
Objects are part of the artificial environment

We shall enable people to compose mixed societies consisting of everyday objects interacting with plants.



Mixed societies = Plants + People

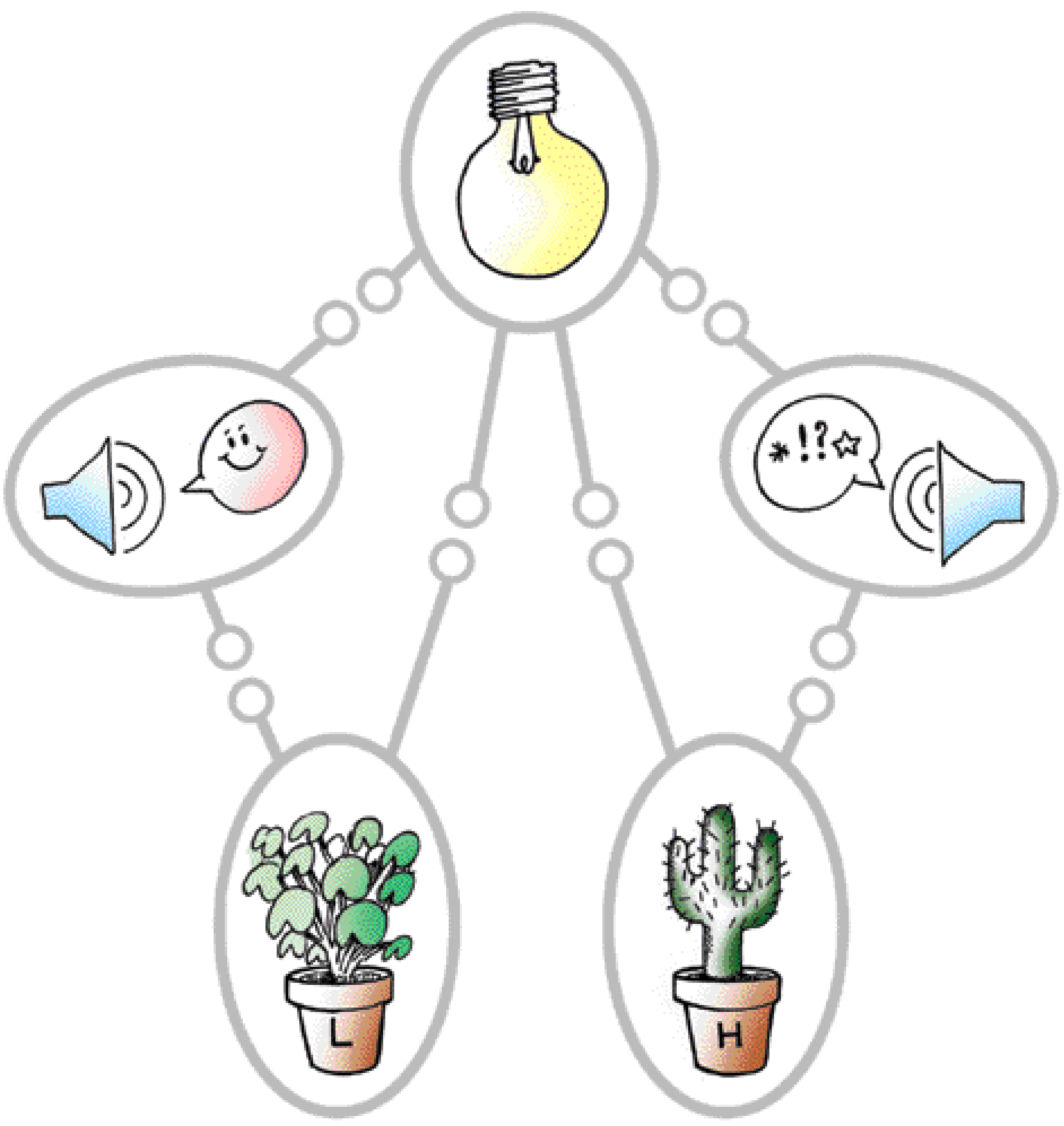
The PLANTS project will:

Key abstractions

1. Develop artefacts that convert plant signals to electrical impulses through wireless communication channels (ePlants);

2. Enable objects to sense their environment by localised computation and communicate with each other, or by interacting with the environment (eGadgets); and

3. Provide the Plug / Synapse model to enable uniform access to ePlant and eGadget services / capabilities / measurements.



Plug
A software abstraction of a property / service offered by an artefact, or a property / ability of a plant

Synapse
A virtual channel between compatible Plugs that enables data and event exchange

bioGadgetWorld
A distributed system formed as a composition of plants and artefacts

Evolution

The current demonstrator incorporates a plant interacting with objects and people in a closed-loop system, designed to relay a sense parameter and respond with corrective measures. This stage involves the:

- Characterisation of specific sensor devices with concomitant analysis of the threshold levels of specific plant signals for biological function;
- Definition of communication channels between the eGadgets and ePlants; and
- Development of ePlantOS, the middleware software layer that implements the Plug / Synapse interaction model.

This demonstrator will be progressed to develop the framework for the interaction of plants with people and with artefacts, moving towards the goal of a distributed system through the simulation of a monoculture crop environment and involves:

- The development of wireless sensor networks and scalable sensor components;
- The seamless integration of software and hardware; and
- Definition of ontology required for the seamless communication between plants, objects and people.

The second PLANTS demonstrator shows the ultimate dissemination goals of the project, demonstrating mixed societies of interacting plants and artefacts, and involves:

- The system sensor networks integrated into contextually-effective artefacts, with a focus upon ease of installation and ongoing user interaction;
- Miniaturised and optimised sensor networks that respond to plant requirements for a number of selected growth parameters;

- Critical appraisal of technology to optimise system performance; and
- Packaging micro-sensors enabling them to carry out their functions in a reliable and repeatable manner in extreme field environments.

PLANTS

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This project was funded under the IST Future and Emerging Technologies program IST-2001-38900

Project web address: **http://www.edenproject.com/PLANTS/**

Plant Stress

Plant Stress Signalling - Application in Precision Agriculture

PLANTS technology has potential applications in the remote sensing of cropparameters in agriculture. Real-time crop monitoring in conjunction with existing delivery systems will enable the more sustainable use of pesticides, fertilizers and water. There is significant need for the development of PLANTS technology because the practical limitations of existing systems include:

- The data may not be available in real-time as this depends on satellite overpass cycles, cloud cover etc;
- Expense; and
- The resolution may not be sensitive enough to detect the early stages of disease development.

Plant monitoring using electromagnetic radiation

Remote sensing using radiation has shown that;

- Crops can be identified by their characteristic spectral emissions;
- Yield can be predicted from electromagnetic radiation;
- Leaf reflectance can be used to measure leaf chlorophyll content (a measure of crop nitrogen status);
- Water stress can be predicted from leaf temperature (desiccation results in stomatal closure subsequently preventing the cooling effect of transpiration – Figure 1); and
- The spread of disease can be monitored based on damage to the leaf canopy (Figure 2).

Fig. 1. The thermal radiation emitted from the leaves is detected to demonstrate water stress stress (leaves on the left).

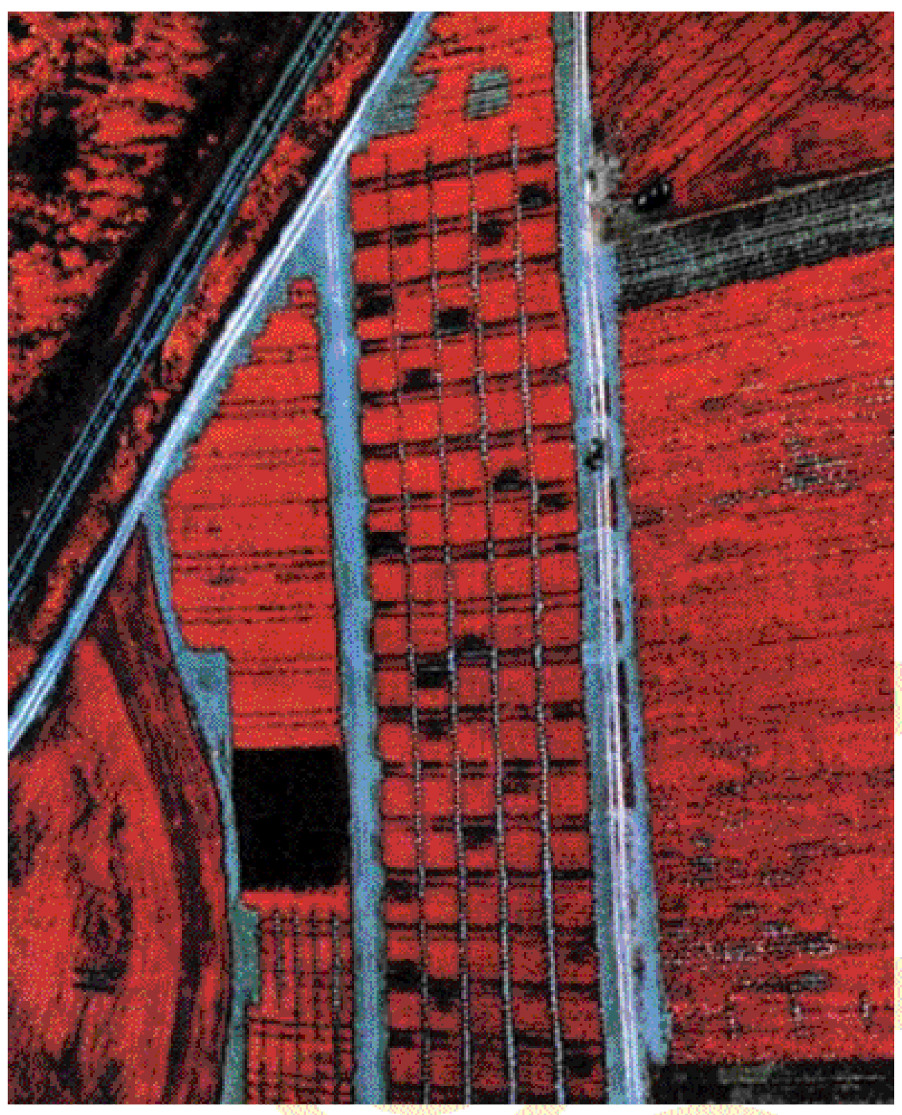


Fig. 2: Infra red image showing the effect of blight on potato fields. Blight shows as black on the image and early blight as green streaks (Image available at URL:http://everest.hunter.cuny.edu/~rnoorzad/ºmapping1-2/rspaper/)

Plant monitoring using chlorophyll fluorescence

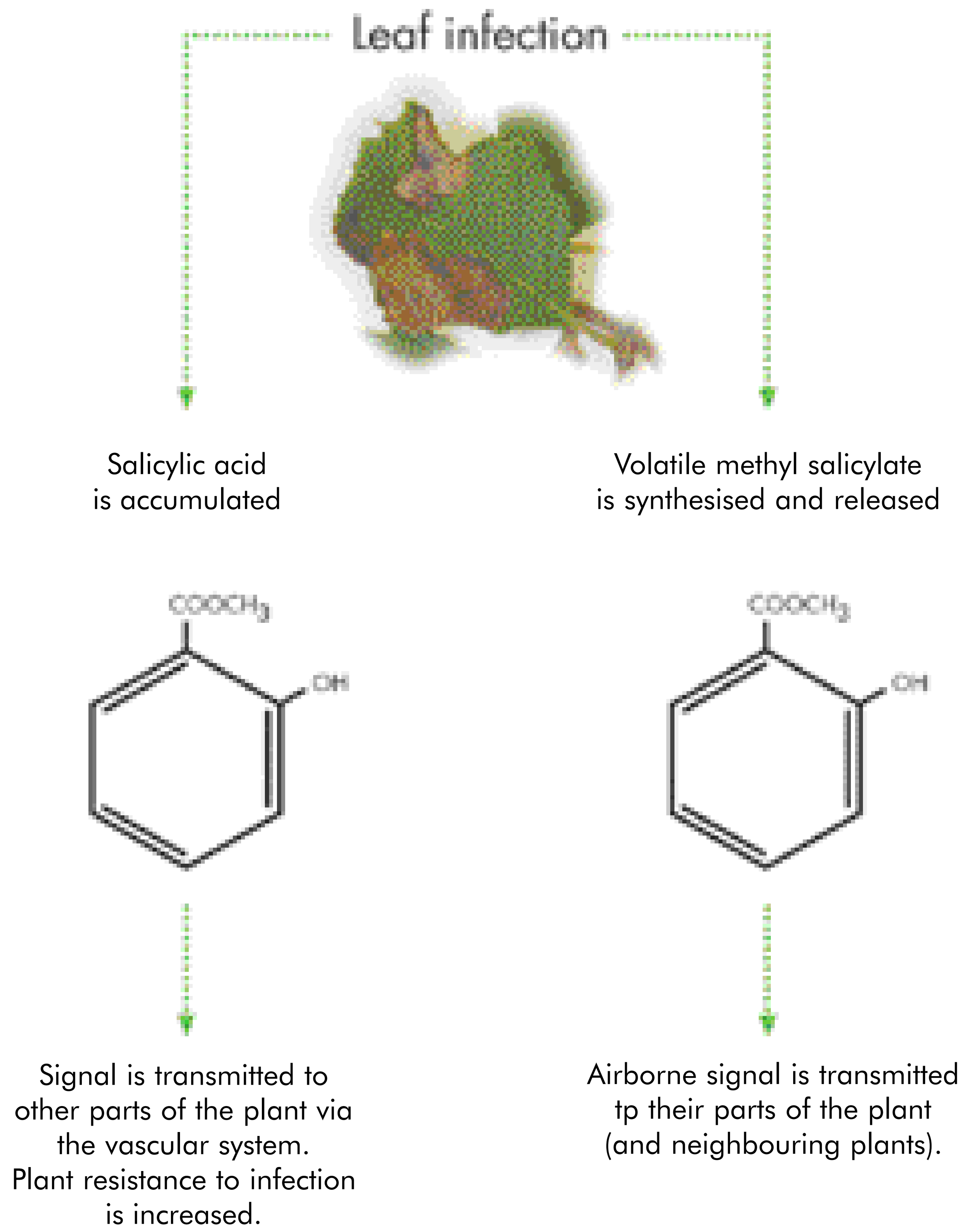
Chlorophyll fluorescence measurements can provide information on photosynthetic efficiency and photo-oxidative, drought and salinity stresses. Monitoring is carried out using modulated light pulses to raise chlorophyll molecules to an excited state. A small amount of the excitation energy is emitted as red fluorescence when the molecules return to the ground state. This release is proportional to photochemistry and heat dissipation, indicative of the range of plant stresses.

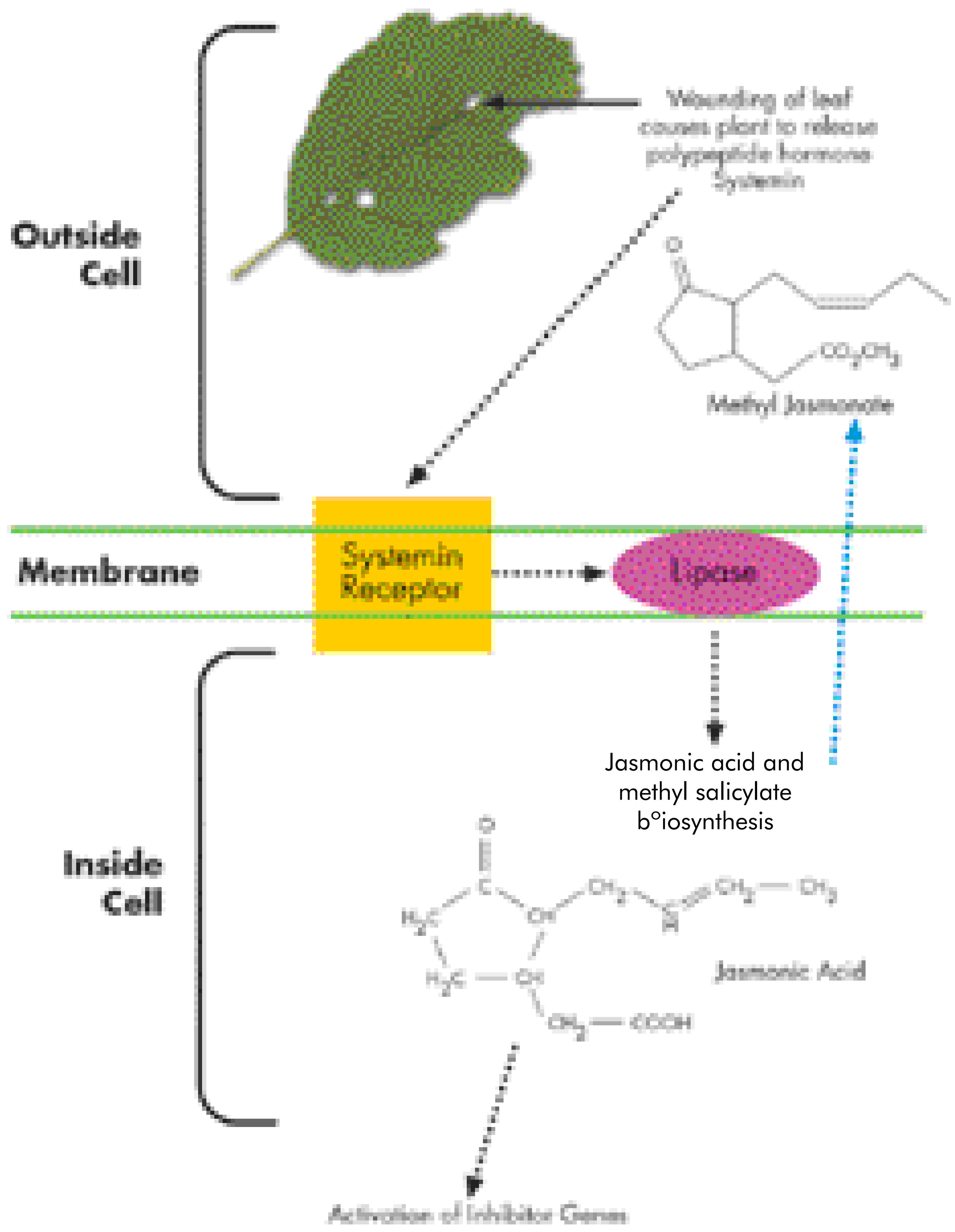
Stress Signals

Volatile organic molecule stress signals

The PLANTS project aims to characterise some of these volatile biomarkers for use in proximal sensing of pathogens and pest. Many other volatile compounds attract pollinators and pest predators. Pathogen-plant combinations produce chemical fingerprints of potential use in detecting and identifying diseased material.

Experimentation will determine whether analysis of these fingerprints can be used in pest and disease forecasting.





Plants produce some universal volatile stress signalling compounds such as ethylene, methyl jasmonate (during pest attack) and methyl salicylate (during pathogen attack) in addition to certain compounds that are specific to species and genera of individual families.

Precision Agriculture

Precision agriculture is a step beyond monitoring the environment to determining the needs of the individual plants within crops

Remote sensing is used in combination with computerised delivery systems to supply fertilisers, pesticides or water to plants that require them. Less efficient broadcast applications that are applied as 'insurance' against pathogen attack, water or nutrient deficits are avoided.

Precision agricultural systems, as represented by the long term goals of the PLANTS project together with strategic plant breeding and biological control, will facilitate the development of more sustainable agricultural systems.

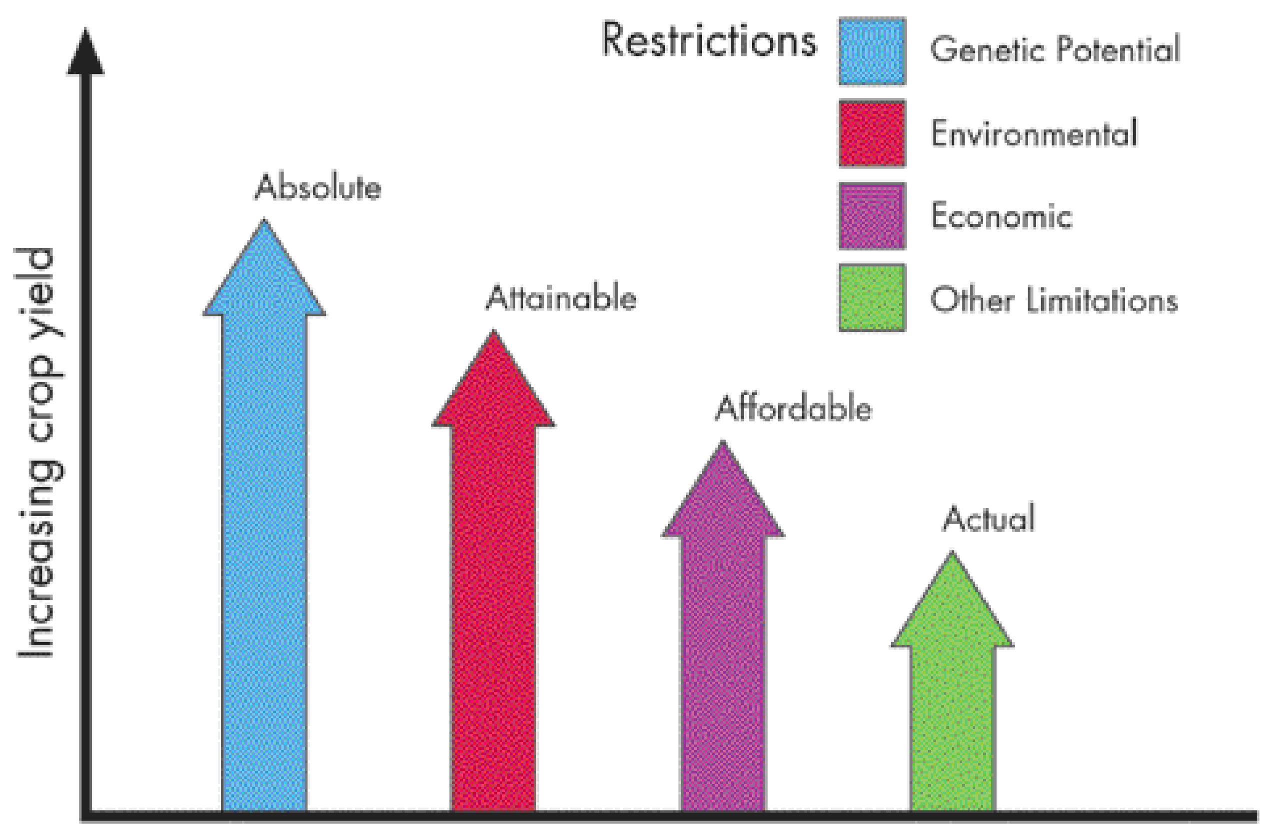


Fig. 1 Further yield increases are possible in many crops where the average yield is less that the genetic potential. Higher yields are achieved at very high input cost in energy, fertilizers, pesticides and in many cases, irrigation. However high inputs have many undesirable side effects including potential pesticide residues in food, effects on non-target organisms, resistance to pesticides, fertilizer run-off and soil salination.

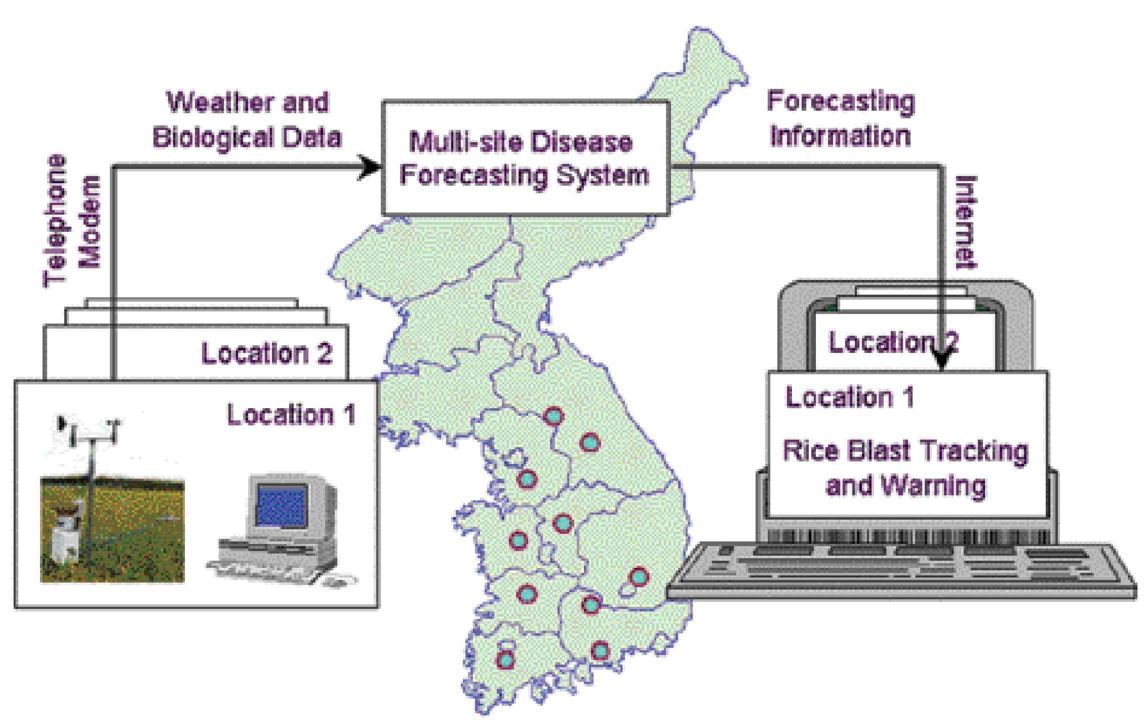


Fig. 2 Forecasting involves the use of on-farm weather stations and has significantly reduced the number of spray applications. These weather stations may be networked to achieve regional management programmes and eventually integrated into a more focused high resolution plant–based sensing system which the PLANTS project is developing..

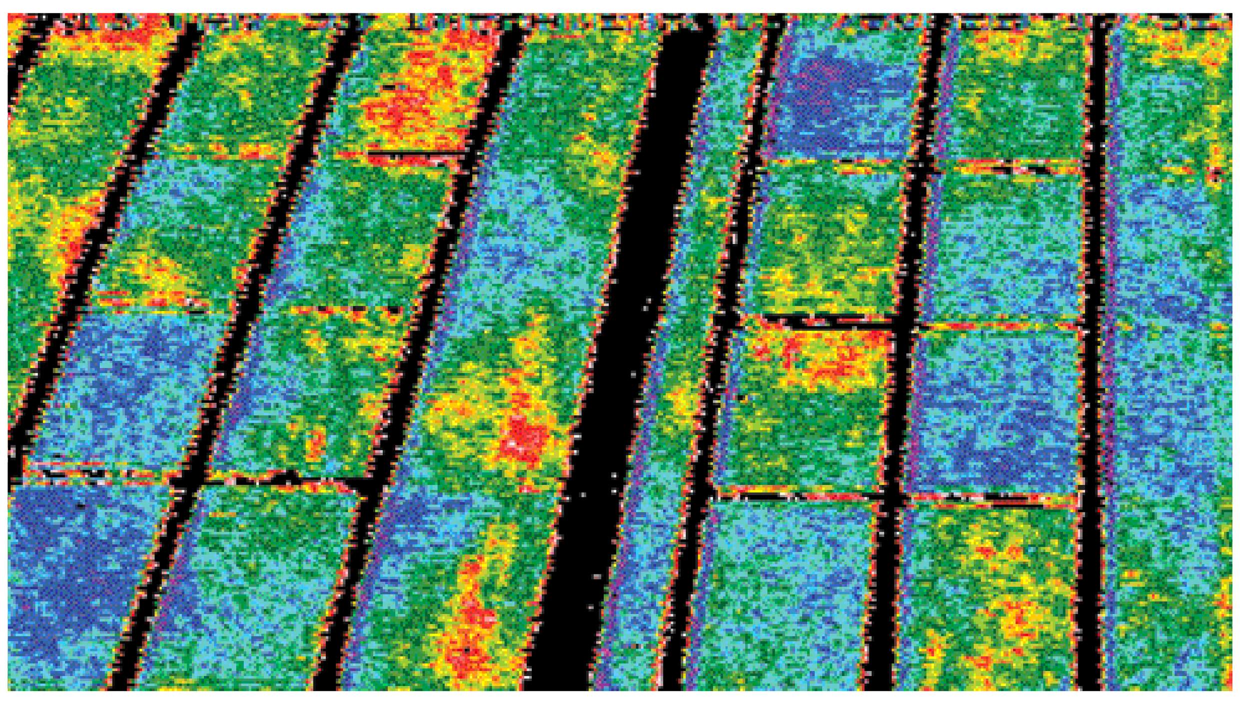
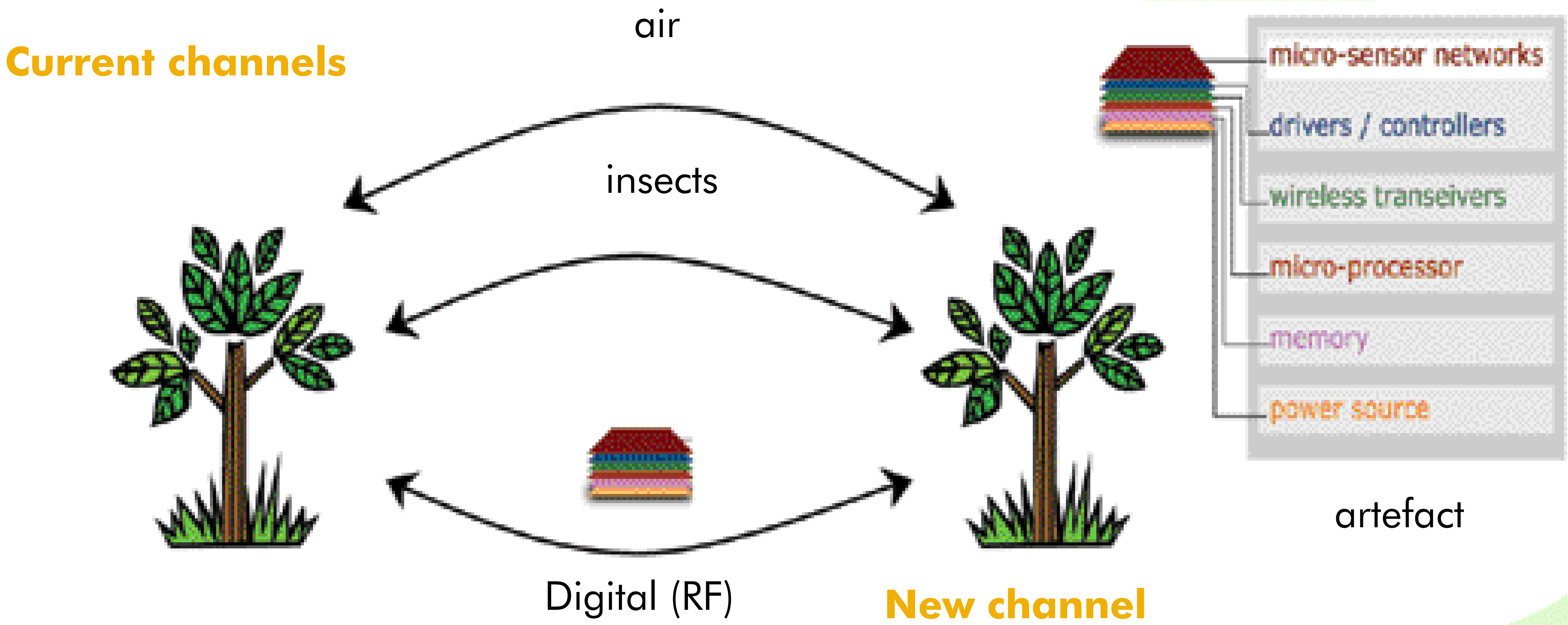


Fig. 3 Satellite surveillance – remote sensing, based on analysis of the spectral emissions of crops, offers new possibilities for crop monitoring and management of regional irrigation schemes. Remote sensing also reveals both between and within field differences. The image indicates an unstressed plant (blue), moderately drought stressed (yellow) and highly drought stressed (red) plants within a crop. (Image from URL: www.uswcl.ars.gov/epd/remsen/irrweb/thindex.htm)

Sensors

The PLANTS project is investigating methods for creating sensor networks between people, objects and plants, to form mixed interacting communities. For this task, plant signals need to be detected using an array of sensors that integrate into the GAS-OS software platform.



The development of these digital channels, that convert biological signals into digital impulses, allow the plant to communicate directly with an artefact (a sensor system with a digital interface) and with the user.

Temperature rise within a leaf is indicative of water stress. Leaf stomatal pores allow the exchange of gases and water vapour (transpiration). This transpiration is stopped by stomatal closure if water levels reach a critical level. Thermography can be carried out using two different techniques, remote sensing by infra-red or by thermisters placed on the leaf, to detect plant water deficit.

PAM 2100, Walz

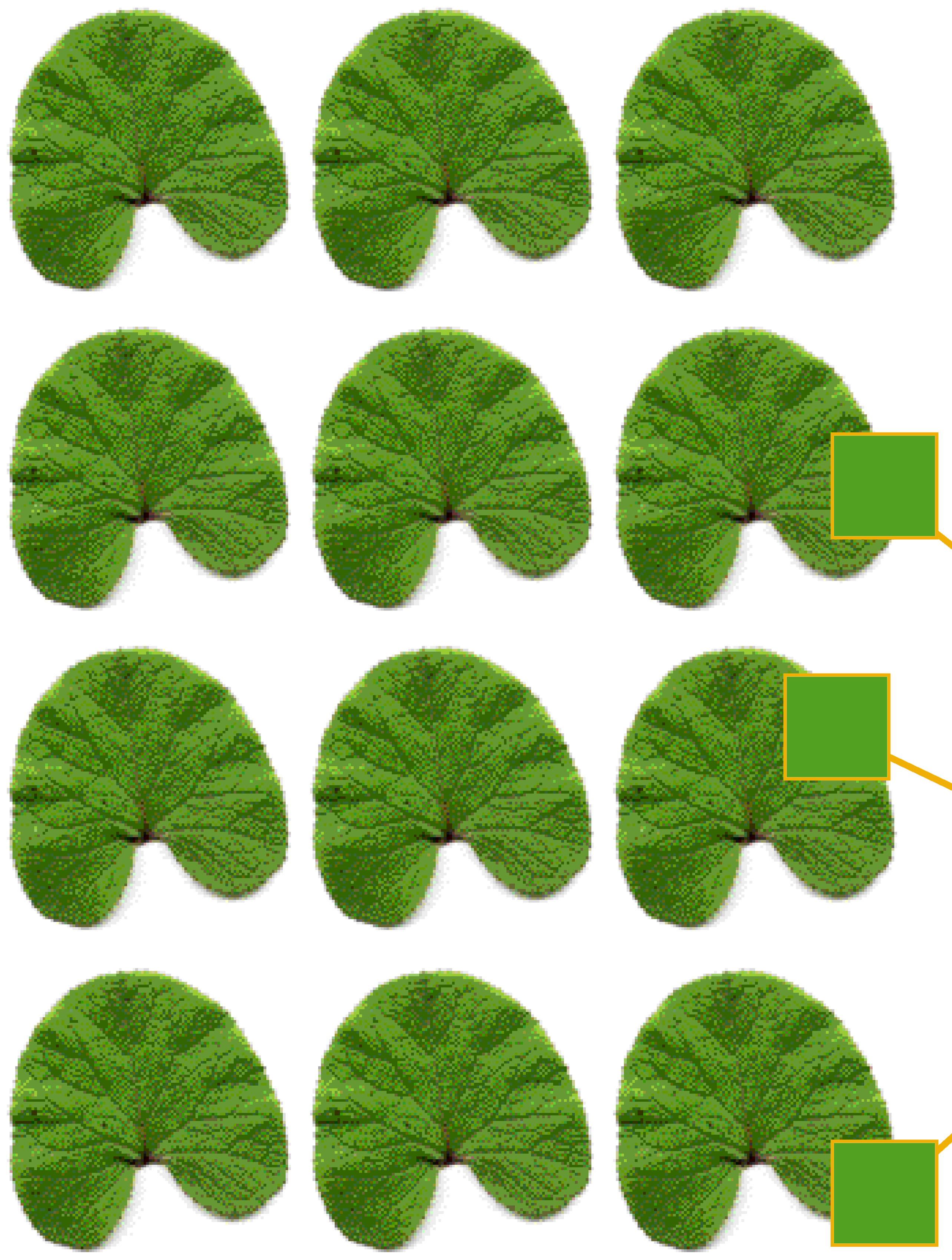
Chlorophyll fluorescence meters determine the level of ambient light required to achieve optimal photosynthetic efficiency (Image available at URL: www.walz.com).

Plants emit a range of volatiles, with different cocktails of these gases relating to the stress response. Commercially available gaseous sensors will be adapted and modified to indicate a plant stress response, by detecting the volatile gases released from the leaves.

PLANTS

Demonstrator

Year two demonstrator vision



Off-Plant Monitoring

(Monitors change in a plant's environment)

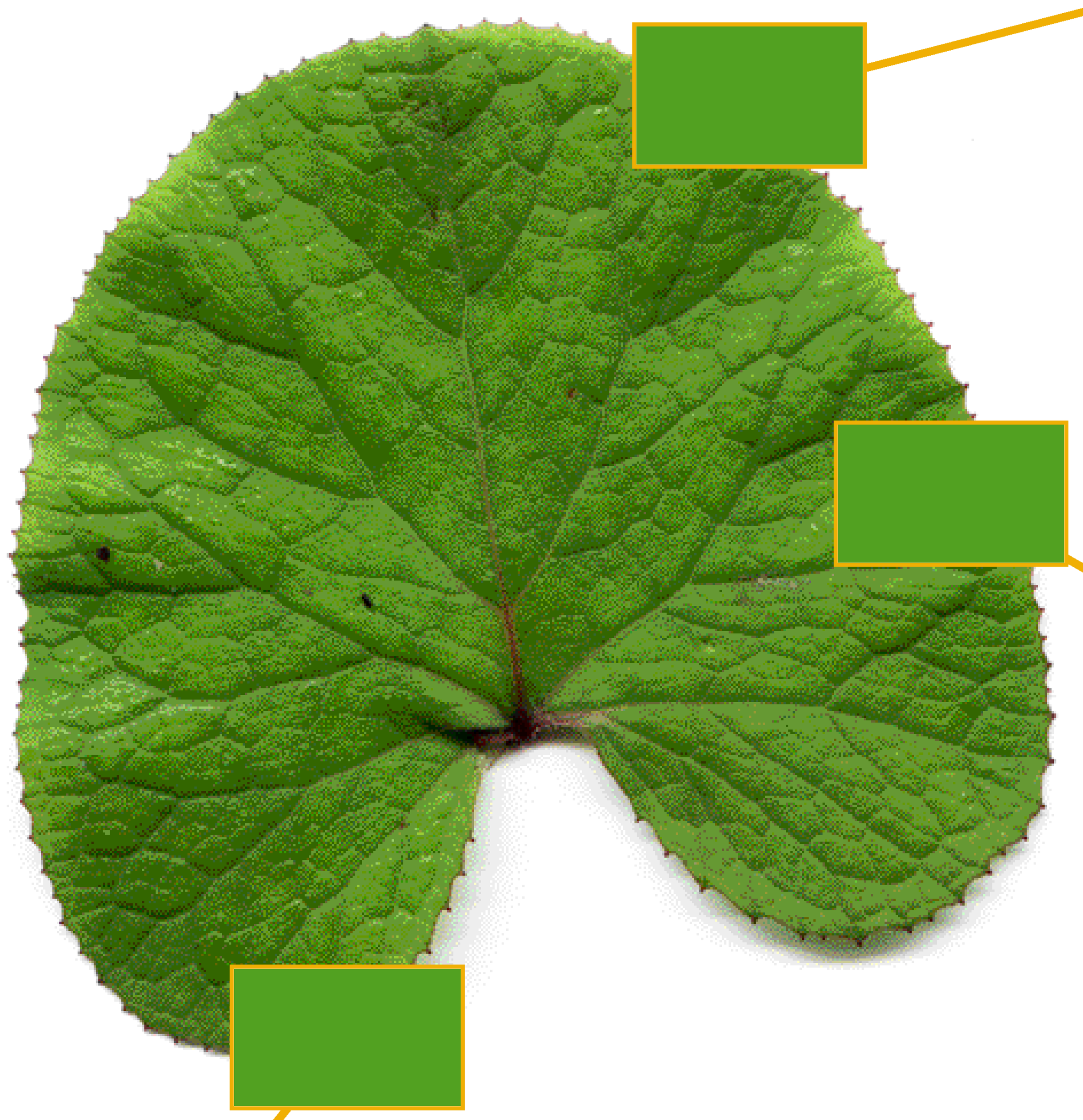
Soil moisture sensors

Soil temperature sensors

Humidity sensors

On-Plant Monitoring

(Monitors change in plant parameters)



Temperature sensors

Water deficit will be detected by either thermistors attached to the plant or by an infra-red (IR) gun placed near the plant.

Chlorophyll fluorometers

Light deficit will be detected by chlorophyll fluorescence attached to non-invasive optic fibres placed on the leaf.

Plant volatile sensors

The development of Commercial Off The Shelf (COTS) components for the detection of specific plant volatile organic molecules will enable identification of plant stress.

State Transition

The following "state transition diagram" illustrates the events, actions and states describing the dynamic behaviour of the Jamboree PLANTS demonstration system