Sensors

A sensor is a device that detects and responds to inputs from the physical environment. Inputs can include any observable element such as temperature, moisture or pressure. The output is generally data that can be translated or processed into information that supports decision-making.

Sensed data is not new in agriculture but advances in technology, including the internet of things, create new opportunities to use data in farm management. Data collected by sensors is referred to as ‘big data’ and requires interpretation by software in a connected device or computer, the transfer to which can be hampered by poor regional telecommunications.

Skills in agriculture may change as farmers base decisions on objective data, rather than physical inspection and observation of crops and livestock. Clarity around who controls and can access the data, as well as the security of data in the cloud, is needed.

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- Data collected by sensors is referred to as ‘big data’ and requires interpretation by software in a connected device or computer, the transfer to which can be hampered by poor regional telecommunications.
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A fact sheet series on new and emerging transformative technologies in Australian agriculture.

Snapshot

- Sensing refers to the detection of physical changes by a sensor.
- Sensors can be mounted on a variety of platforms including vehicles, unmanned aerial vehicles (UAVs) or drones, aircraft and satellites, as well as being placed in soil, water and on plants or animals. In agriculture, sensors also collect data from farm machinery, weighbridges, robotic dairies, weather stations, water pumps and irrigation systems.

Biological sensors (biosensors) use living organisms or biological molecules, especially enzymes or antibodies, to monitor the presence of chemicals in a substance. For example, enzyme biosensors can detect traces of organophosphate residue in farm produce, or biosensors using an acoustic wave platform to trigger chemical reactions can detect bacteria in food.

Remote sensing refers to scans of the landscape from a distance, including by satellite or aircraft. Remote sensing to support precision agriculture is not new but recent advances in wireless sensors using Bluetooth, long-range area networks (WLAN) or mobile phone networks have increased the potential applications of sensors in agriculture.

The substantial amount of information collected by sensors is often referred to as ‘big data.’ When data is classified and analysed to support decisions it is referred to as ‘meta data.’ Discovering practical and meaningful applications of data in agriculture is part of the transition to digital agriculture, where sensors, machines and computers will provide a higher level of accuracy to management decisions.
Agricultural applications

Sensors provide accurate and real-time monitoring of environmental factors that can assist farmers in making better decisions to increase productivity and lower input costs. Already used in some industries, the continuing reduction in price provides more farmers with opportunities to incorporate sensors into their management practices.

Sensors are used in a range of primary industries. They are attached to mining and maritime machinery to monitor and transmit real-time information on performance, providing an early warning when the machinery starts to malfunction. In civil engineering and construction, sensors are used to monitor the structural integrity of infrastructure, like buildings, bridges and dam walls, transmitting data on vibration, pressure and temperature.

CSIRO has developed wearable sensor technologies for use in the mining industry to locate workers in emergency situations. The sensors can also monitor worker health by collecting and transmitting data such as heart rate, core temperature and gas or radiation levels in the surrounding environment.

Producing optimal conditions

Using sensors to monitor greenhouse conditions is standard practice in horticulture. Sensors are placed within crops to ensure temperature, relative humidity and light levels combine to produce optimal growing conditions. Advanced sensors linked to automated control systems can monitor environmental conditions and automate responses, for example temperature regulation and irrigation management.

Sensors can be used to monitor individual plants. Real-time and continuous measurement of stem diameter, sap flow rates, fruit growth rates and leaf temperature can be integrated to support decision-making and provide early detection of plant stress.

Sensors can also monitor growing conditions in the field. Weather monitoring in vineyards allows producers to schedule irrigation, fertiliser applications and harvest. It also provides real-time information to predict pest or disease outbreaks and overnight frosts, providing producers advance warning to implement mitigation.

The University of Sydney has developed a prototype robot, RIPPA (Robot for Intelligent Perception and Precision Application), that uses sensors to classify each plant it detects as a weed or seedling, as it moves through vegetable crops. Based on the data collected, RIPPA autonomously applies herbicide directly to the weeds.

The New South Wales Department of Primary Industries (NSW DPI) is using in-ground sensors in fields of melons, bananas and blueberries to evaluate the effects of compost and biochar on soil condition and crop yield in order to increase soil carbon sequestration and reduce the greenhouse gas nitrous oxide emissions.

Managing animal health and welfare

Sensors can be attached to animals internally, with implants or microchips for example, or externally, with tags or collars. Sensors can also be installed independent of the animal, on infrastructure that animals walk across or past.

Sensors may be designed to provide an early warning of illness. Rumination and activity sensors worn on a collar by dairy cows transmit data on how often the animal is eating, which is a key health and production indicator. In one trial, cows had reduced rumination for 3–6 days before a clinical diagnosis of left displaced abomasum, a metabolic disease in recently calved cows.

The National Livestock Identification System (NLIS) uses a radio frequency identification (RFID) tag to track animal movement along the supply chain from birth to slaughter. The system provides traceability for product integrity and market access, as well as information about livestock movement in the event of a disease outbreak. On-farm sensors can detect the RFID tag when the animal passes by. Introducing additional sensor technology could mean that farmers are able to collect information about each animal’s health and location. This would enable farmers to monitor and regulate herd activity remotely, in real time.
CSIRO is developing thermal remote sensing for use on UAVs to locate and identify livestock in rangelands. The technology will assist cattle producers to improve the efficiency and safety of helicopter mustering, as well as reduce costs.

Sensors are also being used to monitor infrastructure, including the flow and depth of water in troughs, the status of gates and the integrity of electric fences. Being able to transmit data about infrastructure to a farmer’s smartphone or computer means problems are identified immediately, while reducing the need to physically check infrastructure on a frequent basis.

In 2016, CSIRO and Agersens will commence testing the first commercial virtual fence. Using their smartphones, farmers will be able to ‘draw’ digital fence lines on their properties using a global positioning system (GPS) to define boundaries for stock containment and more precise grazing management. Animals will wear a GPS sensor collar that sends a sound or physical stimulus to the animal when it approaches the boundary. Virtual fences also allow wildlife to travel safely through farms without needing to navigate fences.

The Tasmanian Institute of Agriculture and CSIRO have developed a pasture prediction model using sensors and data that provides farmers with real-time information about pasture availability to assist grazing management. NSW DPI is using real-time soil nutrient and moisture sensors, and remotely sensing pasture condition to create models of pasture and dairy production systems to improve nitrogen management.

The Australian salmon industry is using sensors on individual ‘sentinel fish’ to collect real-time data on fish behaviour, as well as water temperature, quality and depth. This information is used to monitor water quality and oxygen levels and regulate feeding, in order to reduce feed wastage and pollution.

Sensors also improve animal welfare outcomes by monitoring livestock during transportation. Sensors can be installed in animal compartments to monitor temperature and humidity, air quality, vibration and animal behaviour during transit. The sensor data can be monitored by the driver, as well as remotely by the livestock’s owner or the customer.

**Using inputs more efficiently**

The emergence of GPS applications in the 1990s delivered efficiencies to grain industries by sensing and collecting on-farm data to support precision farming. Sensors (on satellite, aircraft or farm machinery) can assess crop canopy health to determine fertiliser needs, enabling fertiliser to be applied automatically using variable rate technology.

Sensing technologies have resulted in better information about individual paddock performance, have reduced input costs and improved crop yield. New technologies allow publicly-held climate and soil data to be integrated with sensed data to further refine decision-making.

Australian cotton farmers have used meters and probes to determine soil moisture for many years. In 2016, researchers are trialling canopy temperature sensors, because a plant-based measure of water stress will provide more accurate information for irrigation scheduling than soil moisture.

Sensors are used by irrigation companies to measure and control water within the supply network and for delivery on to farm. Irrigators use on-farm sensors to ensure the accurate application of water to a crop, which reduces costs, waterlogging, waste and reduces the incidence of unaccounted water.

**Delivering quality produce**

Sensors are used to track, trace and monitor fresh produce along the supply chain. This not only ensures quality control of perishable goods; it can minimise the risk of contamination and food poisoning.

In Tasmania, Simplot Australia is trialling sensors in seed potato storage bins to measure CO₂ levels to determine the optimal storage conditions. Annual losses from poor storage are estimated to cost producers more than $6 million per annum. The capacity to monitor storage conditions in real time, will reduce waste and increase farm incomes.

The timber industry uses sensors to monitor timber boards as they dry. This allows millers to understand the optimal time for processing each hardwood board, improving efficiencies and reducing waste.
Sensing change in irrigation

Converting traditional siphon irrigation to a fully-automated system with pipes and gates operated by sensors, has reduced labour costs and improved water use efficiency on a NSW cotton farm.

The issue
Australia’s cotton industry is considered the most water-efficient in the world, producing ‘more crop per drop’ than any other nation. Water is a cotton farmer’s most valuable resource and single-most limiting factor to productivity. As a result growers and researchers continually are looking at new ways to improve efficiency.

Irrigated agriculture can be labour intensive. Cotton is predominantly irrigated by furrow irrigation, where U-shaped siphons are manually activated to transfer water from the irrigation channel into the crop. Siphon activation is wholly dependent on people and requires long hours of repetitive handling and heavy lifting, often in hot weather.

Cotton growers have been quick to adopt moisture probes and sensors and new technology for irrigation scheduling but the siphon technology has not changed in over 30 years.

Cotton grower Steve Carolan runs 2478 hectares of irrigation at Waverley in the Namoi Valley in NSW, with both river and bore water allocations, and his farm manager Andrew Greste believes the benefits of switching to automation are clear.

"Basically, we don't like starting siphons and now we can do a change by phone!"

The technology
Steve and Andrew first saw an automated irrigation configuration at the Australian Food and Fibre’s Red Mill Moree field day, where the National Centre for Engineering in Agriculture (NCEA) and Cotton Research and Development Corporation (CRDC) were conducting automation trials.

In 2015, they converted 100 hectares on Waverley from traditional siphons to a fully automated system, consisting of pipes through the bank and a series of gates in the channel delivery system, which can be remotely opened and closed by mobile phone.

Sensors monitor water levels in channels and in crops, which means water no longer has to be physically checked. Sensors also monitor supply and return channels, so Steve and Andrew know when to turn pumps on and off.

"Not only is it very time consuming to drive around to check pumps and water levels, but remote sensing comes into its own when it is wet and hard to get around the property."

Farmers used to making farm management decisions on their own observations and judgements may find it confronting at first to trust sensors to run their irrigation systems.

"Relying on sensors to tell us what is happening may be a little daunting, but the system has alarms and back-ups so we get a text or e-mail if there is something amiss."

Importantly, the technology is proving to be simple and robust.

"This is turn-key irrigation — we easily irrigated 100 hectares with one man, and he could have easily managed more than five times that."

Decreasing water availability means cotton growers are looking for ways to improve water delivery on farm, beyond using siphons which are labour intensive.
The benefits

Steve says sensors provide a number of benefits, including reduced labour costs, improved crop performance and uniformity, and water use efficiency.

"In terms of water use efficiency these fields have gone from a 36-hour to 24-hour turnaround. Automation also adds flexibility to the system, with the ability to grow other crops because a field set-up like this will be able to be irrigated at any time."

"If we planted wheat on rain moisture and later had water available we could apply an irrigation without having to shift siphons and so on, and we can be more responsive to commodity prices and more easily change what crops we grow and where."

The sensed automation cost $1000 per hectare to install, but provides a relatively quick return on investment.

"This is not cheap to set up but we can justify some of the expense over time in terms of savings in labour and improved water use efficiency. And while we are only one season in, we are seeing signs that all these aspects will be there to justify the system."

Another benefit is having more time available to spend on other areas of farm management, or additional leisure time as a result of not having to manually move siphons. Irrigation could even be managed while farmers take holidays.

The future

The greatest barrier to adoption of sensed automation is cost, however cotton growers who have seen the NCEA and CRDC automation configuration are keen to introduce an element of automation in their systems.

Because sensors can be introduced in stages, it is envisaged that farmers will automate their farms gradually, starting with smaller areas while they assess the benefits and return on investment before making a decision to convert whole properties.

The NSW Government has provided grants for on-farm works, including automated water management and sensing systems, to secure additional water for the environment under the Murray-Darling Basin Plan. This may offset some costs of conversion in future.

The next step for CRDC is developing sensors that can assess a crop’s water needs and automatically adjust irrigation flows, in real time.

Sensors that monitor and deliver water on farm can be operated remotely with a mobile phone, creating more time for other activities.
Farmers are always seeking new ways to improve their efficiency and sustainability. Data collected by sensors will provide farmers with increased amounts of highly accurate information to support decision-making, to increase productivity and profitability.

Existing remote-sensing technologies have provided farmers with insights into the physical characteristics of their farms. Advancements in sensor technologies enable farmers to collect data that measures and monitors their farms on a smaller, targeted scale. This data will be converted into information to drive better decisions and outcomes on farm.

**Better information and decisions**

Sensors transmitting real-time and continuous data will provide farmers with an accurate picture of their farm’s condition. Integrated through an internet of things approach, the sensed information, which can be monitored remotely, will provide farmers with new levels of knowledge about their farm performance. The data will enable predictive information, such as optimum planting and harvest periods, stocking capacity of individual paddocks to enable animals to meet market demand, soil nutrition needs, pest and disease emergence probabilities, and how weather and markets will combine with individual paddock conditions.

The use of sensed information will extend beyond predictive capabilities to monitor individual animal and plant performance and health, in real time. This will include continuous data on individual plant health and stress, quality and yield potential, and animal health, condition and marketability.

Sensors monitoring agricultural machinery will provide performance information to support predictive maintenance, which can be scheduled, rather than impacting productivity when machinery breaks down.

Better information assumes better planning and the ability to implement rapid responses as opportunities or problems are identified. The confidence provided by real-time, objective data on farm performance could mean farmers have more time to spend on higher level, strategic farm management decisions, rather than physical and daily on-farm observations.

**Changed skills and roles**

The increased integration of data into farm management decisions will change the skills required to run successful agricultural enterprises. Initially, farmer skills and knowledge will be supplemented by sensed data but over time, decisions will be increasingly based on objective data, rather than on-farm observations.

Farm advisers and agronomists are already considering how sensed data will change their roles from a focus on farm inspections, to data analysis and interpretation. In many ways, this is a continuing evolution of the adviser role which has always integrated new technologies into advice. For many industries, advancements are incremental, allowing farmers and advisers to develop their skills and knowledge in tandem with the technology.

The advent of digital agriculture may also attract a new generation of people to careers in agriculture, where the science of farming is supplemented by objective data that can be interpreted and implemented with confidence.

Ultimately, sensors may collect and transmit data that is processed through algorithms and artificial intelligence to direct machinery to respond autonomously to the information, without human intervention. Over time, machines may replace humans in some farm management roles.
Increased production and profit
Sensing, as it is currently applied to variable rate technologies, will be expanded to manage the information flow for a wide range of production system components, including crops and livestock. Having access to continuous and real-time data will ensure inputs are used effectively and waste is minimised.

Sensors can transmit data from individual animals including behaviour, body condition score and feeding rates for processing into a nutritional needs analysis, which will ensure optimal feed rates and reduce waste. Sensors can scan crops and send data through algorithms to identify weeds from seedlings and apply herbicide directly on to the weed, reducing the amount of chemical applied across paddock and lessening the economic and environmental impacts of spray drift.

The Australian Farm Institute estimates digital agriculture, through input efficiencies and increased output, will provide gains in the order of 10–15% in cropping systems. While needing additional validation, Meat & Livestock Australia’s preliminary findings on the impacts of digital agriculture suggest productivity gains could be in the range of 4–9% for animal production monitoring and 4–13% for animal health monitoring. In addition, sensing technologies could contribute to digital agriculture delivering a 13–26% productivity gain for soil fertility improvements and 9–11% for better feed allocation in livestock systems.

Natural resource management
Sensing will provide more data which can underpin better decisions for the benefit of plants and animals, and ultimately the environment. Along with the benefits of targeted chemical application that reduce spray drift, sensors can monitor rangeland conditions to limit over-grazing and enhance water quality and soil health.

Sensors in on-farm irrigation systems provide real-time control that improves the economic efficiency of plant and animal systems, by increasing farm productivity with less water and less ecological impact. Sensors in irrigation systems have been progressively improving water management through precise timing and delivery that ensures farmers are getting the exact amount of water when it is required. Basing irrigation events on objective data, rather than estimates, can ensure water is used to achieve its highest economic value and waste is reduced.
Challenges for adoption

The massive amount of data generated by sensors has limited value unless it can be converted to information that supports farm management decisions. Adoption of sensors is challenged by limited connectivity, complex data management and a lack of information about commercial returns.

Many farmers are hopeful that sensors will further improve the efficiencies gained by precision agriculture, which in turn would improve the characteristically slim margins of Australian agriculture. However, tight margins can also delay investment in technology as farmers may be conservative in spending their available capital.

Sensors are an integral part of the broader application of digital agriculture, where they transmit the data to a cloud-based database or an internet of things to translate it into tools or information. It was estimated in 2013, that only 22% of data collected globally was stored in a way that made it suitable for analysis, and less than 5% of that data was analysed. It is estimated that by 2020, the amount of useful data may reach 35% of all data collected, mostly due to the growth of data in embedded systems, including agricultural machinery.

Technical support

One limitation identified in agriculture is a lack of technical support to process data into information. Agricultural industry representatives have stated the lack of existing support personnel for multi-platform precision agriculture technologies already has a negative impact on the Australian grain industry’s productivity, particularly around peak periods of planting and harvest. As at 2016, many sensor applications are in various stages of commercial trials, so companies and researchers are closely involved in supporting farmers with implementation. There are concerns that once applications increase in scale, farmers, agronomists and advisers will not be equipped to translate the data into effective decision-making.

Internet connectivity

If using sensors to transmit data wirelessly, then the quality and capacity of the internet will be important. The difficulty accessing reliable internet in parts of rural and regional Australia is well documented. The NBN’s Sky Muster™ satellite service commenced service in April 2016, which may support more farmers to implement digital agriculture applications. Aside from access to the internet, the capacity of existing internet connections and low levels of downloadable data restrict the gathering and storing of big data. Some Australian farmers are using the 3G and 4G mobile phone network as a proxy for the internet, which comes with its own costs and access issues. The introduction of the 5G network (expected by 2020) will deliver faster internet speeds and increased networking capacity, which may address these issues for some farmers.

Standards and quality

There are no uniform standards for sensors so it is difficult to assess the capacity and value of available products. The only good data is accurate data, so sensors must be robust and reliable. If sensors fail or transmit faulty data, they have the potential to harm business operations. A lack of standards, as well as faulty performance, can slow down adoption as farmers wait for evidence of the value of the technology and identify trusted brands.
Policy and regulation

Across many primary industries, sensors hold much promise in collecting data and providing better information for decision-making. However, farmers require clarity around the ownership and control of data, while the regulation of collection and use of sensed data continues to challenge policy makers.

The growth of the digital economy is a global phenomenon and its impacts are not restricted to agriculture. The internet creates markets that are increasingly global, where funds and information move across national boundaries without regard for domestic law. Predicting the next industry to be disrupted in order to prepare policy frameworks is a challenge for policy makers.

Ownership and access to data

While farmers and industry representatives suggest farmers should own their data for commercial reasons, proponents of digital agriculture suggest the value of data will be in its consolidation into regional sets. Control of data and access to it would normally be covered by contracts but complexity arises with an internet of things, where multiple parties are providing hardware and software to a farmer. The associated parties, for example developers, systems integrators, agronomists, other farmers and telecommunications providers are most likely to be separate entities but all have access to the raw data for interpretation and support purposes.

Big data (collected but not analysed) is low cost, high quality evidence that could be used in compliance or enforcement activities. Access to raw data is one area of concern for industry representatives, particularly where it could be used to make a case against a farmer. Herd health data or grazing data might be used in campaigns to undermine farmers. Banks and insurance companies could inspect predictive yield data before deciding whether to grant an overdraft or to calculate premiums. The potential misuse of data is not fully apparent or understood.

Liability

If it can be proven that sensors are faulty and transmit incorrect data, then the manufacturer would be liable for compensation. If the data is interpreted incorrectly leading to damages or losses on farm it can be assumed that normal liabilities or indemnities relating to operator error would apply.

Complexities exist where sensed data is being transmitted and interpreted by third party software applications or downstream analytics providers. Calibration errors may also occur when the data from a number of sensors and machines are combined to create one piece of information. For example the Australian Farm Institute reported yield sensor calibration errors of ±10% in the US caused by incorrect settings, dirty sensors or GPS errors.

Cybersecurity may also be a problem, particularly if the integrity of cloud-based storages is compromised by virus or hacking events. Malicious software, like the Stuxnet worm, specifically target programmable logic controllers that interface with sensors. Again, it is difficult for nations to make policy in relation to global applications and it is not clear where potential business losses could be recovered in the event of a cyber attack.
Tracking individual animal health using sensors on sheep

Precision agriculture has been a common feature of Australia’s cropping industries for many years. Now livestock producers are getting the chance to use precision technology to improve animal wellbeing and productivity.

The issue

Over the last two decades the Australian sheep industry has focused on building high-value premium lamb and fine wool enterprises. The New South Wales sheep industry is a significant contributor to its state’s economy with a gross value in 2013–14 of $816 million from wool and $640 million from sheep and lambs.

Sheep producers can manage 2000–3000 sheep at any one time but must balance animal welfare and pasture health with market opportunities. Factors like poor nutrition, parasite infection, pregnancy and lambing contribute to an average annual mortality of adult sheep of around 4%. Unseasonal cold snaps aside, lamb mortality is often related to birth weight, which is directly impacted by the ewe’s health and nutrition.

Animal welfare is monitored at key times during the year, such as shearing and weaning, but risks are difficult to manage in large flocks, where animal variability is to be expected and monitoring individual animals is time consuming and difficult.

Producers use their knowledge and experience to monitor sheep flocks but currently there is little objective information that supports on-farm decisions.

The technology

The New South Wales Department of Primary Industries (NSW DPI), in collaboration with the University of New England Precision Agriculture Research Group and CSIRO, is conducting research using sensors on sheep to gather behavioural and location data to establish metrics on individual animals.

Sheep wear a sensor either on an ear-tag or collar that sends continuous, real-time data that researchers analyse to determine key animal welfare, health, productivity and environmental indicators.

Dr Robin Dobos, Research Scientist at the NSW DPI, Beef Industry Centre of Excellence in Armidale, says the project is designed to provide objective and practical information for producers.

“The aim of this program is to identify critical control points in the production system early enough so that producers can implement corrective measures to prevent negative health, welfare and sustainability impacts.”

The data collected from each sheep will eventually evolve into information and tools that producers can use to evaluate a range of factors contributing to on-farm efficiency, including intake and feed efficiency at pasture, behaviour, disease susceptibility and health, reproduction and welfare status, and into applications that improve whole farm profitability, risk management and compliance.

“Used in combination with other sensed data, for example from soil sensors to identify pasture stress, will also enable the farm environment to be monitored and better understood.”

Researchers are performing extensive field tests of available technologies with a view to developing sensors and networks for commercial application on farm.
The benefits

Sensed data transmitted from individual sheep will provide producers with real-time information about the health of their animals and the environment. Using this data in combination with historic production records for that animal, including weight change, body condition and genetic background, will assist producers to improve animal wellbeing and productivity.

Another benefit includes the identification of individual sheep with high reproductive performance, which can be retained for development of the breeding flock.

Further, Dr Dobos explains, integrating weather information and seasonal conditions could provide probabilities of pest or disease outbreaks allowing producers time to mitigate or avoid impacts.

“The technology is already out there and can generate a huge amount of data.”

Temperature sensors could predict illness allowing producers to take preventive measures, and movement sensors could signal feed was low in some areas.

“For instance, it could be used to show if the quality of feed is not good enough as the animal would move about more.”

Tracking animal speed could also be an indication of predation threats.

“Because all of this data can be monitored remotely, it’s also potentially a labour saving device, as producers will be able to spend less time physically monitoring the flock.”

The future

There are a number of research projects using sensors to track individual animal performance underway in Australia, including in the beef and aquaculture industries but Dr Dobos says using sensed data to make on-farm management decisions is still a relatively new concept in Australia’s sheep industry.

“It’s still early days but I can see this technology being used in the sheep industry, in particular, to improve productivity.”

Managing the large amounts of data that will potentially be transmitted continuously by 2000–3000 individual sheep on any one property is the next challenge.

“We now need to work out how to get smaller data sets and analyse that information to make informed decisions.”

Sensed data will give producers unprecedented insights into the individual needs of a property’s entire sheep flock at any one time.

Contact details

Dr Robin Dobos
New South Wales
Department of Primary Industries, Armidale
E: robin.dobos@dpi.nsw.gov.au
T: 02 6770 1824
W: www.dpi.nsw.gov.au
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