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The Algorithmic Gardener’s Field Guide to Pulling Weeds

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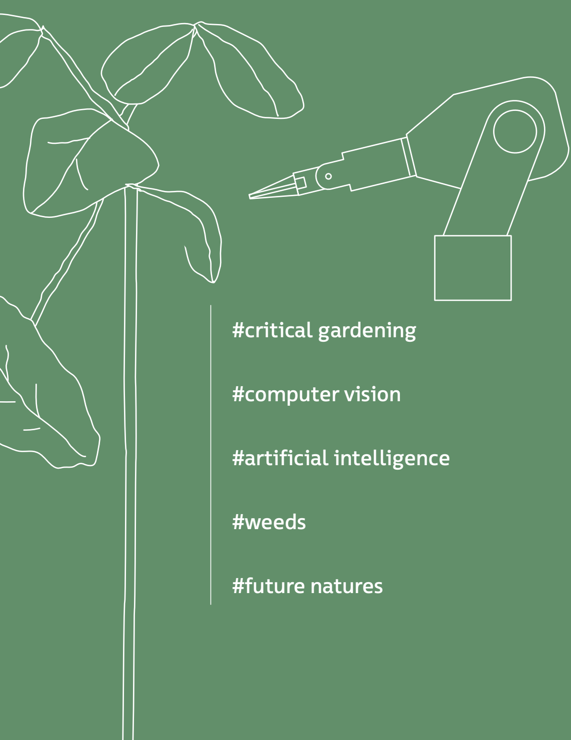
Teach a robot to pull a weed. What sounds like a straightforward task comprises an intricate set of actions and complicated ideas of nature. Translating a culturally-defined, ambiguous object (‘a weed’) into successful machine code directions requires human-machine negotiation and reveals emerging nature-technology relationships.

The field guide provided here contains instructions for a Taurus dexterous robot, commonly employed in tele-surgery and roadside bomb diffusion. The soybean plant, also addressed in the code and images, is an intentional choice based on the combination of agro-environmental, technological and political issues involved in its cultivation globally. As an artistic experiment based on existing technologies, this visual and prose-based algorithmic narrative asks readers to think about how culture and politics are embedded in computer code, and how both algorithms and data structures may manifest themselves in future environmental and agricultural realities.



#critical gardening

#computer vision

#artificial intelligence

#weeds

#future natures

For over a decade we have worked in a collaborative art and research practice we define as *critical gardening*. Inspired by cultural and science studies scholar Chandra Mukerji's study of the gardens of Versailles in the seventeenth century (Mukerji 1997), critical gardening is based on the idea that gardens express ideologies, power structures and cultural concepts. Gardens are active sites for shaping narratives about nature, culture and technology. Through our location at a large research university in the Midwestern United States with strong engineering and agriculture programs, and surrounded by fields of industrial farming, the soybean plant - a contemporary nature-technology hybrid - has become a "central evocative object" (Turkle 2007) in our art practice. This one plant is at the centre of a complex web of interrelated issues that we have critically explored in our works:[1] from historical agricultural and industrial utopias in Henry Ford's *Farm Chemurgy* (Shurtleff & Aoyagi 2020) and his famous *Soybean Car* (the Henry Ford) to contemporary intersections of nature and technology in GMO research; from transnational trade relationships and issues of national security (Pollan 2008) to environmental challenges caused by monocultures and climate change.

The work presented on the following pages grew from imagining the future of robots in farming, following an opportunity to work with an anthropomorphic robot. The two-armed Taurus robot with its stereoscopic computer vision, precision pincers and high level of dexterity is commonly employed in tele-surgery and road-side bomb diffusion (SRI International). At around the same time we started experimenting with the Taurus robot, we were intrigued by an advertisement for Halex GT, the first "herbicide with the work ethic of a machine," (Syngenta United States) as advertised by agricultural technology company Syngenta. We wondered: how might a robot be taught to identify and pull a weed? From the very beginning of the project, we were fascinated by the complexities and cultural idiosyncrasies involved in trying to define a weed and the possible pitfalls (more so than the promises advertised by Syngenta) of translating it into computer code. In thinking about weeds, we were influenced by the work of Austrian artist Lois Weinberger – who creates gardens with weeds that reflect cultures, political systems and environmental conditions (Weinberger 2009) – and the writing of cultural geographer Tim Creswell, who explores a materialist and experientialist understanding of weeds as metaphors (Cresswell 1997). In this context, conceivable divergent outcomes of the robotic weeding process – including what might be construed as mistakes and failures – could provide insight into cultural and social tensions in the production of technical objects.

Our goal was to foreground the otherwise invisible algorithmic instructions that manifest themselves through the robotic actions. In this process we found the work of computer scientist Paul Dourish helpful, investigating code in both cultural and technical contexts as "a site of material, textual, and representational production." (Dourish 2016). The conceptual code in the form of a visual and prose-based algorithmic narrative introduced on the following pages is the result of these investigations. Choosing this alternative and experimental format, we ask the reader to think about how culture and politics are coded into algorithms and data structures, and how computer code may manifest itself in future environmental, robotic labour and agricultural realities (Rhee 2018)[2]. Part 01 of this work explores algorithmic seeing with a focus on the difficulties of translating a culturally ambiguous concept into certain algorithmic "truths" that the robot can use to distinguish between wanted and unwanted plants (Kimmerer 2013).[3] Questioning the construction of "truths" and investigating human-guided machine learning, it shows that human bias can turn to algorithmic bias through the choice of training data sets (O'Neil 2016). What is wanted in one context may not be wanted in another. Part 02 centres on the act of gardening, investigating further our human and (as an extension) algorithmic understanding of plants, for example in the final decision about what to do with the pulled weeds. While our goal was to spotlight the consequences of and dilemmas within otherwise invisible robotic action code, we deliberately meant our algorithmic narrative to elicit questions, rather than provide definitive answers. We hope that by asking those questions, we inspire readers to think about future natures and the role that algorithms and machines may play in them. What will make these future natures desirable and what will make them less desirable? (Dunne & Raby 2013)

In the summer of 2020, we worked with Purdue Department of Theatre graduate students Elizabeth Heaney, Bryan Montemayor and Skyler Tipton on a voice track for the video companion to this field guide to create a dialogue of human and machine voices while showing the Taurus robot identifying and picking weeds in small mobile gardens of soybean plants.

Acknowledgements

The technological steps alluded to here are McMullen_Winkler's interpretations of the explanations offered by industrial engineering PhD student Glebys T. Gonzalez in October 2018 and the experiments in image processing carried out for this project by electrical and computer engineering ME student Arjun Narang in 2016. We thank them for their generous contributions and willingness to participate in this project. Also, this work would not have been possible without the continued support of Dr. Juan Wachs and Purdue University's Intelligent Systems and Assistive Technologies Lab.

All abstractions, omissions and oversimplifications are the fault of the artists alone.

Figure 1: The Taurus dexterous robot prototype addressed in the following algorithmic narrative is equipped with stereoscopic computer vision, two dexterous arms with seven degrees of freedom, and precision pincer appendages able to grip, pull and cut. *Source: Shannon McMullen & Fabian Winkler*

Scan the QR code to watch the video and listen to the song discussed in this contribution.

Part 1

Algorithmic Seeing

```
1    // Look at the garden. What do you see?
2       Create an image data set by recording a garden of
3       soybean plants and weeds over a specified period of time.
4
5       Go through the camera images pixel by pixel, line by line
6       separating background pixels from weed pixels by comparing
7       their color.
8    // What is a plant (background)?
9    // What else do you see in the background?
10
11      Based on this separation, have humans edit and confirm the
12      weed pixels and the background pixels.
13      These labels will be called "ground truth."
14   /* The truth is that plants can be many things. They can be
15      beautiful or architectural. They can provide food or
16      shade. They can be delicious or poisonous. Plants help
17      the earth breathe.
18   */
19
20      Split the labeled images into two groups:
21           a training set and
22           a testing set.
23
24      Discover relationships that define weed pixels:
25            use structured prediction on the training set to
26            label weed pixels based on the distribution of
27            features around them.
28   /* Do you recognize any weeds? A weed is an unwanted plant,
29      or a plant out of place. A weed might also be considered
30      invasive and take over your garden – and your neighbor's
31      garden. A weed is sometimes a metaphor; so is a plant.
32   */
33
34      Use the trained prediction algorithm on the testing set
35      and compare the predicted labels with the ground truth
36      labels.
37      If there is a high level of success in identifying weeds:
38           proceed to Part 2.
39      Else:
40           repeat lines 11–27 until you are very certain and the
41           humans approve
42
43   /* Do you see a weed?
44      Are you sure it is a weed? How sure are you?
45      A bouquet of weeds is not considered a welcome gift, but a
46      bouquet of wildflowers well might be.
47   */
48
49
50
```

Part 2

Algorithmic Gardening

```
// You are now ready to work with live plants.
   Use depth information from the stereoscopic camera to
   position correctly labeled pixels in 3D space and create a
   point cloud model of the weed.

   Generate the coordinates of a picking point for the weed
   by comparing the 3D point cloud model of the weed against
   a model with an annotated picking point.
// Humans will help you here, by supplying models of weeds
// with the best points for picking them indicated.

   Use a path planning algorithm to move the most
   advantageously positioned arm to the picking point.
   While doing so:
        minimize energy expenditure,
        follow the smoothest path available and
        avoid navigating through the soybean plants.
/* Pulling weeds is a tricky business. Grabbing them under
   the leaves at the base where the stems emerge from the
   ground is best. But, if you pull too fast, with too much
   force, and the ground is not soft, you will only snap the
   greens from the roots. In many cases, new stems and leaves
   will sprout from the remaining root.
*/

   Close grippers around the picking point, pull up and move
   the arm to a defined drop point for the weed.
   Avoid moving through the soybean plants.
   Wait for further instructions.
/* What should you do with the weeds that have been pulled?
   Are they:
        trash?
        compost?
        food?
   Fresh dandelion greens, for example – untainted by
   herbicide or lawn chemicals – are tasty and nutritious in
   salads. Bunnies love both the leaves and the yellow
   flowers and so do insects and pollinators.
*/
```

Notes

1 For an overview of McMullen_Winkler's artworks exploring the soybean plant as evocative object see: McMullen_Winkler. Gardens and Machines. Accessed 13 November 2020. http://www.gardensandmachines.com

2 In this sense, our work could be considered an engagement with the robotic imaginary as defined by Rhee. Her work critically examines the gendered and racialised ideas of care labour informing robotic development in the context of the United States.

3 This book provides a deep understanding of the complexity inherent in relations between nature, science and culture.

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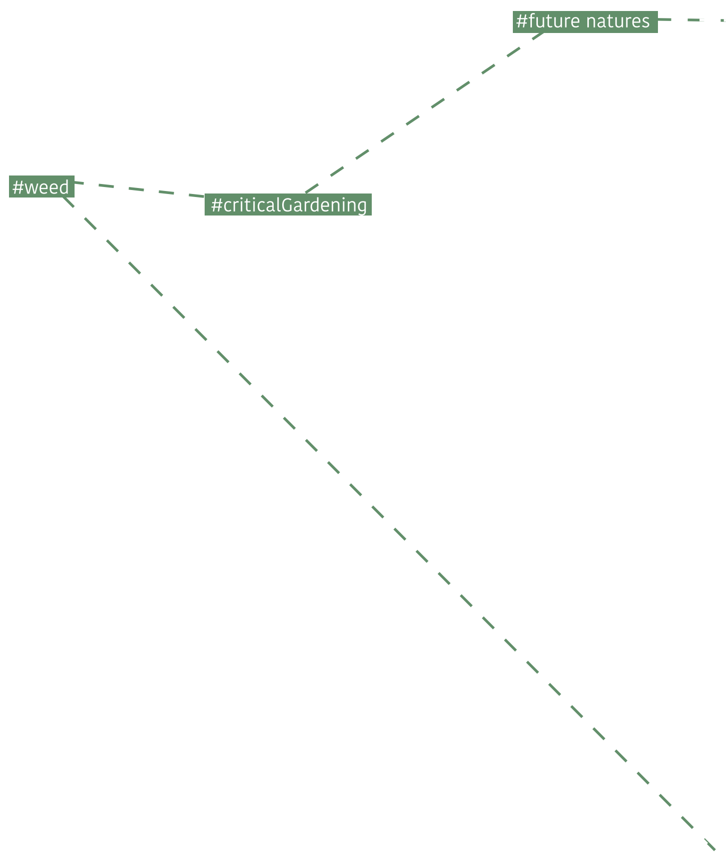
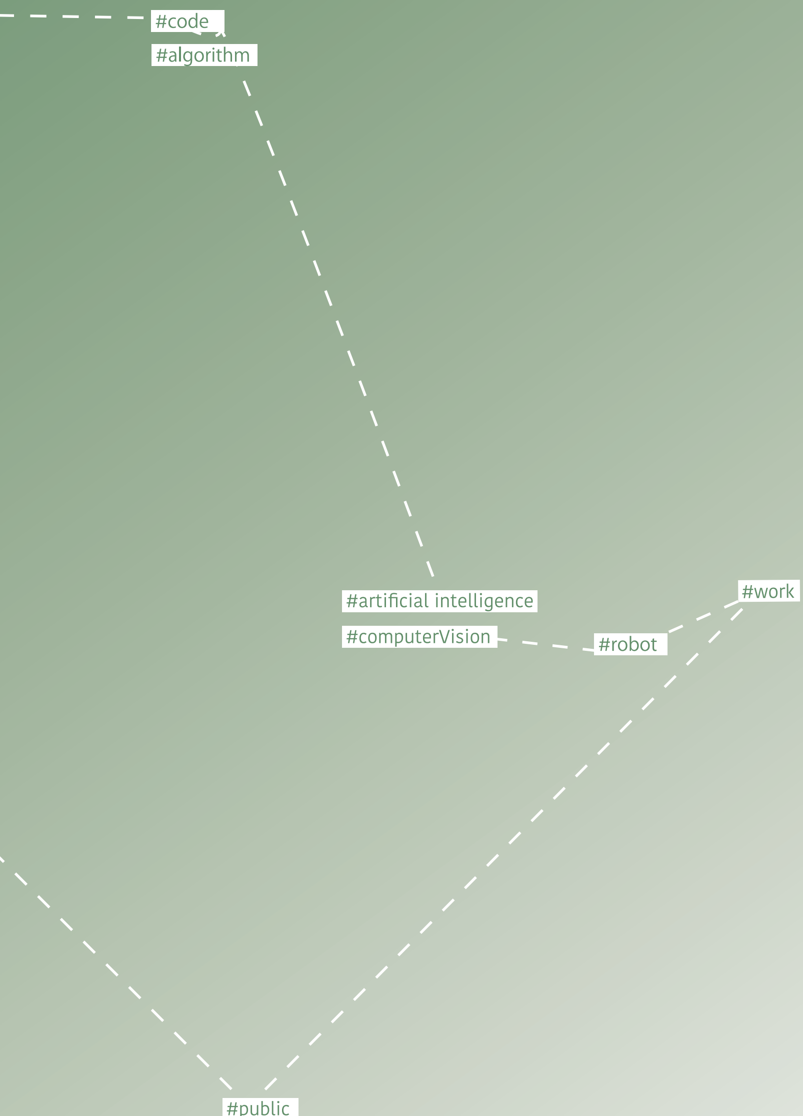
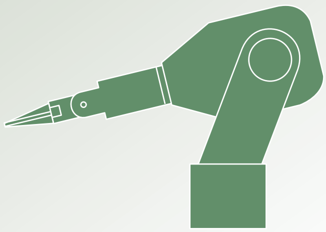
Bio

Shannon McMullen, PhD and **Fabian Winkler, MFA** are interdisciplinary artists and researchers working together as McMullen_Winkler. They combine their backgrounds in new media art and sociology to produce collaborative artworks at the intersection of nature and technology, a research and creative practice they define as critical gardening. Shannon McMullen holds a joint faculty appointment in Art and Design and American Studies at Purdue University. Fabian Winkler holds a faculty appointment in Art and Design. Both teach in the Patti and Rusty Rueff School of Design, Art and Performance at Purdue University in West Lafayette, IN, USA where they co-direct the area of Electronic and Time-Based Art.

Their work has been shown internationally at venues such as the National Museum of China, Beijing; International Documentary Film Festival Amsterdam, NL; Science Gallery Dublin, Ireland; Art Center Nabi, Seoul, Korea; ZKM Center for Art and Media, Karlsruhe, Germany and the Spark Festival, Minneapolis, USA. They have also published articles in *Leonardo* (MIT Press), *Plurale – Zeitschrift für Denkversionen* (Berlin, Germany), *Media-N* (Journal of the New Media Caucus), *Senses and Society* (Berg Publishers) and *The Environmentalist* (Springer, New York). Their large-scale investigation of *Images of Nature* at the intersection of art, engineering and science was awarded a grant from the National Science Foundation.







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