UNDERSTANDING "THE LOOP": REGULATING THE NEXT GENERATION OF WAR MACHINES

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The United States is in the midst of a national debate about the role drone aircraft should play in warfare abroad and law enforcement at home. Armed drones hunt enemies abroad 24 hours a day, seven days a week. Drones have begun to patrol our domestic skies too, on the lookout for suspicious activity.

But contemporary drones are merely the "Model T" of robot technology. Tomorrow's drones will have capabilities once only dreamt about in the pages of sci-fi novels. Today, humans are still very much "in the loop": humans decide when to launch a drone, where it should fly, and whether it should take action against a suspect. But as drones develop greater autonomy, humans will increasingly be out of the loop. Human operators will not be necessary to decide when a drone (or perhaps a swarm of microscopic drones) takes off, where it goes, how it acts, what it looks for, and when it strikes. In the language of engineers, tomorrow's drones are expected to leap from "automation" to true "autonomy."

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As America debates how to deploy and regulate drone technology, this paper argues that regulations for today's drones must be crafted with an eye towards tomorrow's technologies. Yet today's debates about humans and "the loop" rely on language too imprecise to successfully analyze the relevant differences between drones and predecessor technologies. Confusion pervades discussions about when an advanced technological system is autonomous and what the implications of autonomy might be.

This paper helps to resolve this confusion and equip policymakers with the tools necessary to develop thoughtful regulations built on a basic understanding of how drones work. This understanding is critical. Without it, we risk saddling ourselves with laws that protect neither our security nor out liberty. As drone expert Peter Singer notes, drones' "intelligence and autonomy is growing. . . . The law's not ready for all this."

We argue that language useful to the policymaking process has already been developed in the same places as drones themselves — research and engineering laboratories around the country and abroad. We introduce this vocabulary here to explain how tomorrow's drones will differ from today's, outline the policy issues they pose, and suggest possible approaches to regulation. Autonomy is no longer solely a feature of humans. Whether it is a desirable quality for machines to have will be one of the most important public policy debates of the next generation.

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I. INTRODUCTION: AUTOMATION AND AUTONOMY

Drones have revolutionized warfare. They may soon transform civilian life too. America's military efforts abroad are spearheaded by unmanned aerial vehicles—Predators, Reapers, Global Hawks—with capabilities once only dreamed of by science fiction writers. Drones are simply "the only game in town" to fight hard-to-find terrorists in the tribal regions of Afghanistan and Pakistan, according to Defense Secretary Leon Panetta.[1] And drones have already been introduced over our domestic skies, patrolling the U.S.-Mexican border[2] and assisting with law enforcement efforts.[3] Congress has voted to accelerate this trend, directing the Federal Aviation Administration to unshackle restrictions on the domestic use of drones by 2015.[4]

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[1] Peter Bergen & Katherine Tiedemann, *The Drone Wars: Killing by remote control in Pakistan*, THE ATLANTIC (Dec. 2010), *available at* http://www.theatlantic.com/magazine/archive/2010/12/the-drone-wars/308304/ (quoting Leon Panetta, then the Director of the Central Intelligence Agency).

[2] William Booth, *More Predator drones fly U.S.-Mexico border*, WASH. POST, Dec. 21, 2011, *available at* http://www.washingtonpost.com/world/more-predator-drones-fly-us-mexico-border/2011/12/01/gIQANSZz8O_story.html.

[3] Howard Altman, *Drones to patrol skies over Republican convention*, TAMPA TRIB., Aug. 24, 2012, *available at* http://www2.tbo.com/news/republican-national-convention/2012/aug/24/namaino1-drones-to-patrol-skies-over-republican-co-ar-472685/; Nick Paumgarten, *Here's Looking at You: Should we worry about the rise of drones?*, NEW YORKER, May 14, 2012, at 46.

[4] Nick Wingfield & Somini Sengupta, *Drones Set Sights on U.S. Skies*, N.Y. TIMES, Feb. 17, 2012, *available at* http://www.nytimes.com/2012/02/18/technology/drones-with-an-eye-on-the-public-cleared-to-fly.html.

As amazing as today's drones may seem, they are merely the "Model T" of robot technology.[5] Most are souped-up, remote-controlled airplanes; they still have a human pilot, but he or she now sits at a military base rather than in the cockpit. Today's drones do not think, decide, and act on their own. In engineering speak, they are merely "automated."

Tomorrow's drones are expected to leap from automation to "autonomy." Those sophisticated machines will have the ability to execute missions without guidance from a human operator. And they will increasingly be used alongside — as well as in the air above — people. Drones will augment civilian life: some countries are experimenting with robotic prison guards[6] and in-home caregivers.[7] Robotic warehouse workers, ambulance and taxi drivers, and medical assistants are in the works, too.[8] These and other innovations will join continued military and law enforcement use of drones.

Today's automated drones raise difficult policy questions, but those questions will seem pedestrian compared to the issues created by tomorrow's autonomous systems. This Article argues that regulations for today's drones should be crafted with an eye toward tomorrow's technologies. Policymakers must better understand how the next generation of autonomous drones will look compared to today's merely

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[5] PETER W. SINGER, WIRED FOR WAR: THE ROBOTS REVOLUTION AND CONFLICT IN THE 21ST CENTURY 110 (2009) [hereafter SINGER, WIRED FOR WAR].

[6] James Trew, *Robo-Guard the South Korean Correction Service Robot Says "stay out of trouble"* (video), ENGADGET, April 15, 2012, *available at* http://www.engadget.com/2012/04/15/robo-guard-south-korean-robotic-guard/.

[7] Sally Abrahams, *Robot Caregivers?*, AARP BLOG (April 19, 2012), *available at* http://blog.aarp.org/2012/04/19/technology-helps-caregivers/.

[8] Nick Bilton, *Disruptions: At Amazon, the Robot World Comes a Little Closer*, N.Y. TIMES, Mar. 25, 2012, *available at* http://bits.blogs.nytimes.com/2012/03/25/disruptions-at-amazon-the-robot-world-comes-a-little-closer/.

automated machines. This paper explains the vital distinction between automation and autonomy, and sets out a roadmap for regulating the next generation of war machines.

Today, humans are still very much "in the loop."[9] Humans generally decide when to launch a drone, where it should fly, and whether it should take action against a suspect. As drones develop greater autonomy, however, humans will increasingly be "out of the loop." Human operators will not be necessary to decide when a drone (or perhaps a swarm of microscopic drones) takes off, where it goes, how it acts, what it looks for, and with whom it shares what it finds.

Today's debate about humans and "the loop" relies on language that is too imprecise to successfully draw out and analyze the relevant differences between drones and predecessor technologies. But bringing better terms and greater rigor to these discussions is challenging. It is difficult to agree on a definition of "autonomy" even when the word is applied to humans.[10] Autonomy has been variously described as "a combination of freedom and responsibility . . . a submission of laws that one has made for oneself,"[11] as the state achieved when one "is acting from principles that we would consent to as free and equal rational beings,"[12] and as a "second-order capacity of persons to reflect critically upon

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[9] *See* Bernd Debusmann, *More drones, more robots, more wars?*, REUTERS, Jan. 31, 2012. *See also* Shane Harris, *Out of the Loop: The Human-free Future of Unmanned Aerial Vehicles* (Hoover Institute 2012), *available at* http://media.hoover.org/sites/default/files/documents/EmergingThreats_Harris.pdf; Markus Wagner, *Taking Humans Out of the Loop: Implications for International Humanitarian Law*, 21 J.L. INFO. & SCI. (forthcoming 2011), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1874039.

[10] GERALD DWORKIN, THE THEORY AND PRACTICE OF AUTONOMY 7 (1988).

[11] ROBERT PAUL WOLFF, IN DEFENSE OF ANARCHISM 14 (1970) (describing the theories of Immanuel Kant).

[12] JOHN RAWLS, A THEORY OF JUSTICE 516 (1971).

their first-order preferences, desires, wishes, and so forth."[13] Various forms of autonomy appear in the Supreme Court's decisions on controversial and deeply divisive issues, including sex,[14] contraception and abortion,[15] and the existence and scope of a right to die.[16] "About the only features held constant from one author to another," one thinker despaired, "are that autonomy is a feature of persons and that it is a desirable quality to have."[17] Small wonder that confusion pervades discussions about when an advanced technological system is "autonomous," and what the implications of autonomy might be.

The stakeholders in debates about the appropriate uses of drones are varied,[18] the technology is developing rapidly,[19]

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[13] DWORKIN, *supra* note 10, at 20.

[14] *See*, *e.g.*, Lawrence v. Texas, 539 U.S. 558, 562 (2003) ("Liberty presumes an autonomy of self that includes freedom of thought, belief, expression, and certain intimate conduct. The instant case involves liberty of the person both in its spatial and in its more transcendent dimensions.").

[15] *See*, *e.g.*, Gonzales v. Carhart, 550 U.S. 124, 170 (2007) (Ginsburg, J., dissenting) ("In reaffirming *Roe*, the *Casey* Court described the centrality of 'the decision whether to bear . . . a child,' to a woman's 'dignity and autonomy,' her 'personhood' and 'destiny,' her 'conception of . . . her place in society.'") (citing Eisenstadt v. Baird, 405 U.S. 438, 453 (1972)) (internal citations omitted)).

[16] *See*, *e.g.*, Washington v. Glucksberg, 521 U.S. 702, 726 (1997) (reversing the Court of Appeals, which had concluded, "Like the decision of whether or not to have an abortion, the decision how and when to die is one of the most intimate and personal choices a person may make in a lifetime, a choice central to personal dignity and autonomy." Compassion in Dying v. Washington, 79 F. 3d 790, 813-14 (9th Cir. 1996)).

[17] DWORKIN, *supra* note 10, at 6.

[18] *See*, *e.g.*, Andrew Stobo Sniderman & Mark Hanis, *Drones for Human Rights*, N.Y. TIMES, Jan. 30, 2012, at A25, *available at* http://www.nytimes.com/2012/01/31/opinion/drones-for-human-rights.html.

and the resolution of questions like these will reverberate on a global scale.[20] Without a basic understanding of the technology driving the key issues and a common vocabulary to engage those issues, domestic and international policymakers risk speaking past one another and causing frustration, if not hostility. As drone expert Peter Singer notes, drones' "intelligence and autonomy is growing. . . . The law's not ready for all this."[21]

As we argue here, language useful to the policy and lawmaking process has already been developed in the same places as drones themselves — research and engineering laboratories across the country and around the globe. In this Article, we introduce this vocabulary to explain how tomorrow's drones will differ from today's, we outline the policy issues tomorrow's drones pose, and we suggest possible approaches to regulation.

Part II of this Article provides a detailed discussion of how drone decision-making works, and explains the distinction between automation and autonomy. Part III tracks the development of drones past, present, and future, and demonstrates through examples how drones are expected to evolve from automated to autonomous machines. Part IV highlights the difficult policy questions posed by tomorrow's drones, and explains how policymakers can use this Article's model of autonomy and of drone decision-making to craft smart, targeted regulations that protect both our security and our privacy. Part V concludes.

Autonomy is no longer solely a feature of humans. Whether it is a desirable quality for machines to have will be

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[19] *See, e.g.,* SINGER, WIRED FOR WAR, *supra* note 5, at 109–22.

[20] *See*, *e.g.*, W.J. Hennigan, *New Drone Has No Pilot Anywhere, So Who's Accountable?*, L.A. TIMES, Jan. 26, 2012, *available at* http://articles.latimes.com/2012/jan/26/business/la-fi-auto-drone-20120126.

[21] Paumgarten, *supra* note 3, at 48 (quoting Singer).

one of the most important public policy debates of the next generation.

II. MACHINE FUNCTIONING AND THE DIFFERENCE BETWEEN AUTONOMY AND AUTOMATION

To explain autonomy and how it differs from automation, we first explore how machine decision-making processes operate. The "OODA Loop"[22] is a particularly effective tool for understanding complex systems, including aerial drones carrying lethal payloads, for it offers a language shared by engineers, the military, and the public.[23] When commentators debate whether drone warfare leaves humans "in the loop," "out of the loop," or simply "on the loop," it is the OODA Loop they are talking about.[24]

A. Understanding "the Loop": OODA and How Machines Work

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[22] For detailed discussions of John Boyd's development of the OODA Loop, see generally FRANS P.B. OSINGA, SCIENCE, STRATEGY AND WAR: THE STRATEGIC THEORY OF JOHN BOYD (2006); GRANT T. HAMMOND, THE MIND OF WAR: JOHN BOYD AND AMERICAN SECURITY (2004); ROBERT CORAM, BOYD: THE FIGHTER PILOT WHO CHANGED THE ART OF WAR (2002).

[23] See United States Air Force, *Unmanned Aircraft Systems Flight Plan, 2009–2047*, at 16 (2009), *available at* http://www.fas.org/irp/program/collect/uas_2009.pdf [hereafter Air Force Flight Plan] (arguing that "[o]ne of the most important elements" that will drive the United States Air Force's increased reliance on unmanned aerial vehicles (UAVs) "is the potential for [UAVs] to rapidly compress the observe, orient, decide, and act (OODA) loop").

[24] See Harris, *supra* note 9; Wagner, *supra* note 9. The Air Force Flight Plan projects that "[i]ncreasingly humans will not longer be 'in the loop' but rather 'on the loop'—monitoring the execution of certain decisions." Air Force Flight Plan, *supra* note 23, at 41.

Why did American F-18 fighter planes get the better of Soviet MiG-5 jets during the Korean War? Air Force pilot and military strategist John Boyd's answer to this question transformed the military's approach to victory in battle.[25] Boyd's insight was that in a dogfight, the advantage lay with the fighter pilot who could make faster and more accurate decisions than his opponent, and who was able to throw his opponent's decision-making "loop" out of sync.[26]

Boyd distilled human decision-making using a four-step process: *O*bserve, *O*rient, *D*ecide, *A*ct.[27] In Boyd's "OODA Loop," a person first *observes* the world around her, gathering data about her environment through the array of human senses.[28] Second, she *orients* herself, or interprets the information she has gathered.[29] Third, she weighs the potential courses of action based on the knowledge she has accumulated and *decides* how to act.[30] Fourth and finally, she *acts*, or executes the decision she has made.[31]

Boyd's elegant theory is still used by the military today.[32]

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[25] Berndt Brehmer, *The Dynamic OODA Loop: Amalgamating Boyd's OODA Loop & the Cybernetic Approach to Command and Control*, at 2 (remarks at the 10th Annual International Command & Control Research and Technology Symposium 2005), *available at* http://www.dodccrp.org/events/10th_ICCRTS/CD/papers/365.pdf; Scott E. McIntosh, *The Wingman-Philosopher of MiG Alley: John Boyd and the OODA Loop*, 58 AIR POWER HIST. 24, 26–28 (2011).
[26] McIntosh, *supra* note 25, at 26–27.
[27] CORAM, *supra* note 22, at 334.
[28] Brehmer, *supra* note 25, at 2; McIntosh, *supra* note 25, at 27.
[29] *Id.*
[30] *Id.*
[31] *Id.*
[32] For example, the Marine Corps' *Warfighting* manual discusses the OODA Loop and endorses Boyd's view that "the party who consistently completes the cycle faster gains an advantage that increases with each cycle." See U.S. Marine Corps, *Warfighting*, at

It has gained purchase in other fields too, including in business, sports and engineering — "anywhere a competitor seeks an edge."[33] Engineers have borrowed the concept to illustrate the way machine systems operate, make decisions, and interact with the world.[34] For example, Thomas Sheridan, an engineer and a leading scholar of autonomy and robotics, suggests a four-stage information-processing model which tracks OODA: (1) Information Acquisition; (2) Information Analysis; (3) Decision Selection; and (4) Action Implementation.[35]

The OODA Loop is not without flaws. Even its proponents admit that the four-stage model is a "gross oversimplication" of both human and robot information processing, in part because the four stages overlap in time.[36] The "loop" is not a clean linear process, for it includes constant feedback and integration among the different stages.[37] Still, the OODA Loop provides a useful lens for understanding system design.[38] It also permits a relatively

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40 n.18 (1997), *available at* http://www.dtic.mil/doctrine/jel/service_pubs/mcdp1.pdf.

[33] McIntosh, *supra* note 25, at 26.

[34] See, e.g., Eric Sholes, *Evolution of a UAV Autonomy Classification Taxonomy*, at 1 (remarks at the 2007 IEEE Aerospace Conference), *available at* http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4161585.

[35] Gilles Coppin & François Legras, *Autonomy Spectrum and Performance Perception Issues in Swarm Supervisory Control*, 100 PROCEEDINGS OF THE IEEE 590, 592 (2012), *available at* http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06108329; Raja Parasuraman, Thomas B. Sheridan, & Christopher D. Wickens, *A Model for Types and Levels of Human Interaction with Automation*, 30 IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS PART A SYSTEMS AND HUMANS 286, 288 (2000), *available at* http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=844354.

[36] Parasuraman et al. *supra* note 35, at 288.

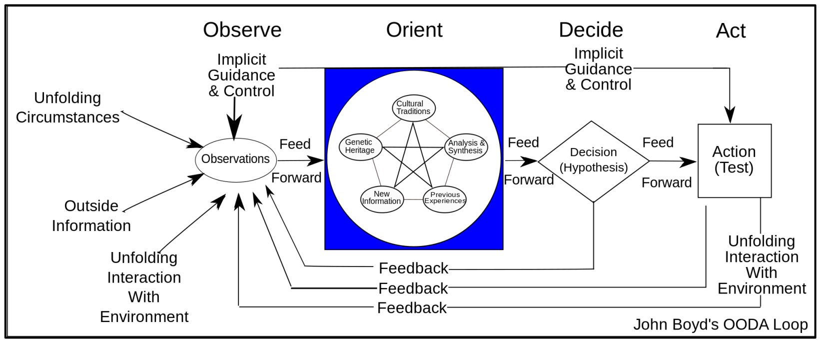
[37] *Id.*

[38] See Coppin & Legras, *supra* note 35, at 593.

straightforward comparison of systems based upon their technological capabilities.[39]

In all its complexity, the OODA loop appears as follows:

FIGURE 1 — Boyd's OODA Loop[40]



To see how the OODA Loop works in practice, begin with a human being — call him Dave[41] — who is walking down a road and encounters a large boulder blocking his path. Dave must get past the boulder. Described using the OODA Loop framework, Dave first *observes* his surroundings, using all his senses to take in the world around him. He sees the boulder with his eyes and ascertains its height (can he step or jump over the boulder?), gauges its density (can he push it aside?), and observes the path on either side of the boulder. He also uses his senses of hearing, smell, touch, balance, temperature, and perhaps even taste, to absorb as much information about his environment as possible.

Dave then *orients* himself by synthesizing the information he has observed and begins to convert it into knowledge upon

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[39] *Id.* at 593.

[40] Wikipedia, OODA loop, http://upload.wikimedia.org/wikipedia/commons/thumb/3/3a/OODA.Boyd.svg/2000px-OODA.Boyd.svg.png (as of Aug. 23, 2012, 18:00 EST).

[41] *See* 2001: A SPACE ODYSSEY (MGM 1968) (Dave Bowman: "Open the pod bay doors, HAL." Hal: "I'm sorry, Dave. I'm afraid I can't do that.").

which he can act. He may determine, for instance, that the boulder is too heavy to push aside and too tall to scale, but note that there is open space to the left of the boulder.

Next, Dave *decides*. He weighs his options: he could retreat and go back, or he could attempt to scale the boulder, albeit not without risk of physical injury. After reflecting, Dave decides to take the open path to the left of the boulder. Finally, Dave *acts*. By moving his legs and walking to the left, past the boulder, Dave is able to continue down the path.

This description of Dave's encounter with the boulder may seem labored and didactic. That is precisely the point. These tasks are complex and require many mental and physical processes. Yet under normal conditions, humans may be able to perform the entire OODA Loop subconsciously and, depending on the act and its context, almost instantaneously.

But if we now consider how a machine might interact with the same boulder, we can begin to understand the many technological processes the machine must execute to get past the rock in the road. Our machine — call him Hal[42] — must first *observe* its surroundings. This task, simple for Dave, is apt to be far more difficult for Hal. Hal must be built to sense the world around it, with the ability to identify and classify objects. Hal needs more than the raw capability to sense what is before it: it also needs some scope of vision, so that it can identify both the boulder immediately in front of it and the land on either side.

Without the capacity to observe its environment and collect these details, Hal may not be able accurately to understand possible paths around the boulder. Observational deficiencies at the first stage in the OODA Loop will curtail the options available to Hal later in the process. Depending on the characteristics of Hal's environment, the sensing process may be more or less complex. Incomplete or inaccurate observations increase the risk that Hal will err in the course of achieving its objective, potentially dooming its mission. As

[42] *See id.*

the saying goes, "garbage in, garbage out" — or, to use the OODA Loop, faulty information at the *observe* stage affects the rest of the process.

Next, Hal must *orient* itself, or transform its observations into conclusions. This requires Hal to weave together many independent data points into a coherent portrait of the world around him. Here, processing speed is also a factor. While Dave may be able to orient himself and make inferences based on his observations without breaking his gait, Hal might not be equipped to absorb and incorporate all the information flooding its processors from its sensors at once. Hal may have to slow down or even come to a complete stop while it orients; if it is too slow, it may simply crash into the boulder.

Next, Hal must *decide* which action to take. This is perhaps the most difficult stage of the OODA Loop for a machine to execute. Hal's ability to make complex decisions will depend on its technological sophistication. Hal's decision-making ability could be very basic and rudimentary. For instance, Hal could be programmed such that if it identifies a roadblock ahead, it simply stops in its tracks and calls its human operator for help. Or, a more complex and varied menu of options might be possible. For example, upon identifying a roadblock, Hal could be programmed to turn left 90 degrees, advance five feet, and then turn right. It is also possible to structure decisions in sequence. If Hal decides after executing the pre-programmed maneuver that there are no more roadblocks, its instruction might be to move forward. In contrast, if the roadblock persists, Hal's programming might dictate that it move five more feet to the left, until the machine's sensors show that the path ahead is clear. Identifying possible actions is only half the battle. The machine must still make the *best* decision in light of the information available, probably taking into account a range of factors like safety, speed, and efficiency.

Having made its decision, Hal must then *act*. As with the three prior stages of the OODA Loop, Hal's range of possible actions is limited by its technological design, just as Dave's abilities are limited by his biology. Dave is not likely to be able to fly over the boulder, for instance — though Hal, depending on its construction, perhaps could. If Hal lacks arm-like appendages, it cannot move the boulder. If Hal is a land-bound rover, it cannot jump over the it. And Hal's ability to go around the boulder will be limited if it is not equipped to traverse the terrain on either side successfully.

These encounters with Hal and Dave show that a machine's capacities may vary significantly at each stage of the OODA Loop. A machine's ability to perform all four stages of the OODA Loop — and to go through those stages with speed and accuracy — turns on the technology built into it. Depending on the state of the art, Hal may be better at observing than deciding, or better at acting than orienting.

Hal, of course, is a stand-in for any sort of robot, including drones. The more Hal, or a drone, can achieve by itself through automated processes, the less the machine may need to communicate with an operator for instructions or recommendations in order to augment the capabilities the machine lacks with human senses, organic thought processes, or analytic evaluation. As the distance between the machine and its operator increases and the amount of interaction between the human and robot decreases, however, even action that is ultimately only the result of layers of complex and refined processes operating in tandem with one another — highly advanced automation — may begin to look qualitatively different. It is most often at this stage that the question of whether the machine is "autonomous" is raised.

B. Toward a Distinction Between "Autonomy" and "Automation"

Whatever might be said about humans, all machines are not created equal. Compare the 1983 Apple Lisa to the contemporary MacBook, or weigh the capabilities of a Cold War era U-2 spy plane against those of the surveillance and combat drones of today and tomorrow.[43] In each case, it is evident that the latter differs meaningfully from the former. It is less clear whether the distinction represents a quantum leap or a linear advance. Debates about drones reflect the intuition that advanced machines are qualitatively different by ascribing to them, sometimes without careful evaluation, the characteristic of "autonomy." We suggest instead that the best way to evaluate whether and how these machines actually are different is to study the distinction between "automation" and "autonomy" more carefully.

Engineers can evaluate a machine's level of autonomy by measuring its level of dependence on humans while executing the OODA Loop. The greater the machine's ability to observe, orient, decide, and act on its own, the greater its autonomy.[44] Yet while the terms "automation" and "autonomy" are alike in that both "refer to processes that may be executed independently from start to finish without any human intervention,"[45] the processes' differences are more revealing than their similarities. Automated systems are not self-directed. They also lack decision-making capability. Instead, these systems simply have "the capacity to operate without [human intervention]."[46] By contrast, autonomous

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[43] See *infra* Part III.

[44] See SINGER, WIRED FOR WAR, *supra* note 5, at 74 ("That a machine can make a decision on its own, with or without a human in the loop, does not define whether or not it is a robot. The relative independence of a robot is merely a feature called 'autonomy.'").

[45] WALT TRUSZKOWSKI ET AL., AUTONOMOUS AND AUTONOMIC SYSTEMS: WITH APPLICATIONS TO NASA INTELLIGENT SPACECRAFT OPERATIONS AND EXPLORATION SYSTEMS at 10 (2009), *proof available at* http://eprints.ulster.ac.uk/2581/1/book-last-preproof.pdf.

[46] O. Grant Clark et. al., *Mind and Autonomy in Engineered Biosystems*, 12 ENGINEERING APPLICATIONS OF ARTIFICIAL INTELLIGENCE at 10 (1999), *available at* http://www.sciencedirect.com/science/article/pii/S095219769900010X.

entities are capable of being "independent in the establishment and pursuit of their own goals."[47] An automated process "simply replace routine manual processes with software/hardware ones that follow a step-by-step sequence that may still include human participation.[48] An autonomous one has "the more ambitious goal of emulating human processes rather than simply replacing them."[49]

Automation is both a precursor to and a crucial component of autonomy. Engineers define autonomous systems as having "independence of comportment," which is possible when the machine "can be described as possessing, to some degree, several defining characteristics."[50] "The first characteristic is *automation*: the capacity to operate without outside intervention."[51] Yet autonomy alone is insufficient to create an autonomous machine.[52] Autonomy also requires some decision-making agency, captured by the two additional characteristics of *volition*, or "choice in action or thought," and *intent*, or deliberate "pursuit of goals."[53] Truly autonomous machines may also be able to actually learn, meaning they can draw conclusions based on past experience

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[47] *Id.* at 2.
[48] TRUSZKOWSKI ET AL., *supra* note 45, at 10.
[49] *Id.*
[50] Clark et al., *supra* note 46, at 10.
[51] *Id.*
[52] *Id.*
[53] *Id*. The technical definitions provide here track dictionary definitions of autonomy. "Automation" is defined as "[t]he technique of making an apparatus, a process, or a system operate automatically," or "[a]utomatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor." MERRIAM-WEBSTER ONLINE DICTIONARY, http://www.merriam-webster.com/dictionary/automation. "Autonomy" is defined as "[t] he quality or state of being self-governing; especially: the right of self-government." *Id.* at http://www.merriam-webster.com/dictionary/autonomy.

and incorporate these lessons into future actions.[54]

This baseline distinction between automation and autonomy offers a useful starting point, but more is still needed.[55] Autonomy is a complex concept with many components that cannot be captured simply through a distinction based on decision-making independence. Capsule definitions are too simple because there is no bright-line distinction between automated and autonomous technologies. The better approach, therefore, is to define autonomy in terms of "common sets of traits" which apply across types of machine systems."[56]

Three traits define the degree to which a machine is merely automated or truly autonomous: (1) the *frequency of operator interaction* that the machine requires in order to function; (2) the machine's ability to function successfully notwithstanding *environmental uncertainty*; and (3) the machine's *level of assertiveness* as to each one of the various operational decisions that allow the machine to complete its mission.[57] By understanding these three attributes of autonomy, we can begin to understand what it means for a machine to be autonomous rather than just highly automated.

1. The first attribute of autonomy: Frequency of operator interaction

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[54] See SINGER, WIRED FOR WAR, *supra* note 5, at 75–77.
[55] See TROY JONES & MITCH LEAMMUKDA, REQUIREMENTS-DRIVEN AUTONOMOUS SYSTEM TEST DESIGN: BUILDING TRUSTING RELATIONSHIPS 1 (The Charles Stark Draper Laboratory, Inc. 2011), *available at* http://www.itea-wsmr.org/ITEA%20Papers%20%20Presentations/2010%20ITEA%20Papers%20and%20Presentations/itea_lvcc_2010_uast_track2_draper_jones_leammukda_paper.pdf (noting that "[t]here are as many definitions of 'autonomous systems' as there are papers that define it," but arguing that all of these definitions are "incomplete").
[56] *Id.* at 2.
[57] *Id.* at 2–10.

The first attribute of machine autonomy is the frequency with which an operator must interact with the machine – in shorthand, a machine's "independence." Autonomous machines require less frequent of operator interaction than automated machines. In an extreme case, the operator could merely press "go" and leave the machine to execute the entire mission without further human intervention.[58] The more frequently the operator must give the machine commands, the less autonomous and more merely automated the system becomes, until it finally "degenerate[s] into an entirely remote-controlled system."[59]

Revisit Hal and the boulder. Assume that Hal's goal (as set out by its human operator) is to travel one mile down the road, and that Hal encounters the boulder mid-way through the trek. If Hal can autonomously complete the mission, the operator need not help Hal get around the boulder. Instead, Hal would independently observe its environment, orient itself, decide to go around the boulder's left flank, and execute the movement. At the other extreme, imagine that Hal is a remote controlled robot, like a remote-controlled car or hobby plane. In this scenario, Hal would require continuous interaction with a human to move down the path. If the human stops giving commands to Hal, the machine will be unable to proceed.

There is a broad middle ground between true autonomy and complete automation. Perhaps Hal is able to independently proceed straight down the road, but if it encounters any potential obstacles, it is programmed to stop in its tracks and request operator permission to change course and turn left to get around the boulder. Or perhaps the human operator has veto power over Hal's decisions, such that the human is *permitted* but not *required* to interact with Hal. Hal's dependence upon a human operator might also vary across each of the four stages of the OODA Loop. All of these

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[58] *Id.* at 5.
[59] *Id.*

configurations turn on the frequency of operator interaction. Each one represents an intermediate position between complete automation and true autonomy.

2. The second attribute of autonomy: Tolerance for environmental uncertainty

The second attribute of autonomy is a machine's tolerance of environmental uncertainty – in shorthand, a machine's "adaptability."[60] The critical issues here include the system's capacity to detect and avoid collisions with objects in its environment, as well as the range of obstacles the system is capable of confronting.[61] A machine with high adaptability to environmental uncertainty is able to accommodate and navigate a wide range of scenarios, including ones not previously encountered in a laboratory setting. In contrast, a machine with low tolerance for uncertainty may be able to operate optimally only in a narrow band of environments. It will have substantially slower reaction times in novel settings, assuming it can respond at all. Depending on its adaptability to environmental uncertainty, a machine may be more or less autonomous.

Hal's ability to function successfully may vary a great deal based on its capacity to adapt to environmental uncertainty. At one extreme, it might have no "eyes" or other sensors at all. So configured, Hal would be blind, unable even to tell that there is a boulder, much less to decide to avoid it. At the other extreme, Hal could be equipped with sophisticated perceptive sensors and advanced, highly flexible processing capabilities. Together, this might permit Hal to navigate the terrain around the boulder without regard to whether Hal's programmer had anticipated obstacles of the boulder's specific size and mass. The ability to understand and adapt is critical to Hal's capability to act autonomously. If Hal cannot detect boulders

[60] *Id.* at 2.
[61] *Id.*

but is used in a quarry, for instance, a human will be required to steer it.

As with frequency of operator interaction, Hal's capacity to navigate in uncertain environments may vary along the different stages of the OODA Loop. Hal's ability to manage unfamiliar environments clearly is tied to its ability to *observe* its environment. But tolerance for environmental uncertainty matters at other stages in the OODA Loop, too. For example, if Hal has a low tolerance for environmental uncertainty, it may be unable to recognize that previously known objects have moved since its last visit. Similarly, if Hal cannot specifically identify the objects around it, it might not be able to identify the full range of possible decisions available to it. The higher a machine's tolerance for environmental uncertainty, the more it will tend to approach true autonomy.

3. The third attribute of autonomy: Level of assertiveness

The third attribute of autonomy is a machine's level of assertiveness, or its ability to change its operating plan in order to complete its assigned mission without guidance from a human operator. In shorthand, this attribute is a machine's "discretion."[62] The gravamen of assertiveness is the system's ability independently to alter the *means* it uses to achieve the human-designed *ends*. A system approaching true autonomy may even have the authority to alter the *ends* that it will pursue without human intervention.

When Hal encounters the boulder, it could react in many different ways. In a scenario where the machine has a high level of assertiveness, Hal could be instructed simply to reach a destination a specified distance away, and given both the capability and the authority to eliminate any obstacles in its path. On the other hand, Hal could have a very low level of assertiveness. Hal's programmers might instruct it to travel

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[62] *Id.* at 9.

forward on the road but stipulate that if the robot encounters any obstacles, it must stop immediately and await further instruction. The higher Hal's level of assertiveness, the more vigorous and potentially creative its attempts to complete its mission in the face of obstacles may be.

Hal's level of assertiveness determines its ability to progress autonomously from one stage of the OODA Loop to another. A machine's level of assertiveness affects its ability and authority to *decide* how to act. The breadth of Hal's freedom to choose among potential courses of action affects the degree to which Hal may alter the mission plan, as defined by its programmer or operator, or even the mission objective itself.

Notice the link between assertiveness and risk. A machine's assertiveness is most directly implicated when the machine becomes "stuck" — for instance, when its "decide" processes report that no movements are possible. An assertive machine may be more successful in finding ways to get "unstuck," perhaps by taking a risk and executing an action that might not have a high probability of success.

For example, imagine Hal concludes that the only way past the rock is to jump over it, but that Hal's leap enjoys only an 80% chance of success and a 20% likelihood of crashing and damaging itself or its surroundings. Stipulate that under normal circumstances, Hal will only evaluate actions with a 90% likelihood of success at the *decide* stage. If Hal is unassertive, it will stop in its tracks, retreat, or call for human help. But a more assertive machine, determining that the only way to complete the mission is to jump over the rock, might lower its threshold of success for this particular decision and attempt to leap over the boulder. The higher level of assertiveness, the closer the machine draws to true autonomy.

C. The Autonomy Spectrum

By now, it should be clear that there is no bright line between "automation" and "autonomy." Instead, autonomy is a function of the three variables just described: independence, adaptability, and discretion. A system is autonomous when it acts with sufficiently infrequent operator interaction, when it is able to function successfully in unfamiliar environments, and when it achieves mission objectives with a high level of assertiveness.

Still, there is no line in the sand. One group of robotics engineers argues that "[l]ike intelligence and consciousness, autonomy should be measured on a continuous scale,"[63] or a spectrum. Some systems would clearly lie on the "automated" end of such a spectrum, like a robot welding doors in a Ford Motors plant. Other systems might be closer to autonomous — think of a futuristic drone able to seek, identify, and kill an enemy without any human interaction. Most systems, however, will fall somewhere between these two extremes, just as with the many different versions of Hal discussed above. In some versions, Hal is operated like a tool. In others, the robot more closely resembles a teammate.[64]

Thomas Sheridan, the engineer and scholar introduced above, has developed a 10-level spectrum of autonomy that illustrates the absence of a clear line dividing automated from autonomous systems, and the difficulty of defining precisely when a system moves from automated to autonomous.[65] On Sheridan's spectrum, at Level 1 a machine is automated; at Level 10, it is fully autonomous. At any other level, the system is somewhere in between. Note that Levels 2 through

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[63] Clark et al., *supra* note 46, at 10.

[64] *Cf.* Johnson et al., *The Fundamental Principle of Coactive Design: Interdependence Must Shape Autonomy* 172, *in* COORDINATION, ORGANIZATIONS, INSTITUTIONS, AND NORMS IN AGENT SYSTEMS VI, Vol. 6541 (2011), *available at* http://www.springerlink.com/content/a54371r947t2n453/; *see also* Bradshaw et al., *From Tools to Teammates: Joint Activity in Human-Agent-Robot Teams*, *in* HUMAN CENTERED DESIGN, Vol. 5619 (2009), *available at* http://www.springerlink.com/content/l12348134205684h/.

[65] Parasuraman et al., *supra* note 35, at 287.

4 focus on the allocation of decision-making authority between the human and machine. By contrast, Levels 5 through 9 grant the initial decision-making authority to the machine and give the human operator varying levels of approval or veto authority.[66]

TABLE 1 — Sheridan's 10 Levels of Autonomy[67]

Level	Description
1	The computer offers no assistance, human must do it all.
2	The computer offers a complete set of action alternatives, and
3	Narrows the selection down to a few, or
4	Suggests one, and
5	Executes that suggestion if the human approves, or
6	Allows the human a restricted time to veto before automatic execution, or
7	Executes automatically, then necessarily informs the human,
8	Informs the human after execution only if the human asks, or
9	Informs the human after execution if it, the computer, decides to do so.
10	The computer decides everything and acts autonomously, ignoring the human completely.

Applying Sheridan's 10-level spectrum requires attention to one important wrinkle: a machine's autonomy can vary along each stage of the OODA Loop. A machine might exhibit a great deal of autonomy in observing its environment and orienting itself, but be dependent on humans at the decision and action stages.[68]

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[66] Coppin & Legras, *supra* note 35, at 592.
[67] See Parasuraman et al., *supra* note 35, at 287.
[68] Parasuraman et al., *supra* note 35, at 289; Sholes, *supra* note 34, at 1.

When the Air Force Research Lab (AFRL) released its own 11-level autonomy spectrum, it took this crucial fact into account.[69] Note too that the Air Force spectrum was developed in part to further an understanding of autonomy in situations where a single human operator controls multiple unmanned air or ground vehicles.[70] Thus, it considers the autonomy of multiple-machine systems.[71]

TABLE 2 — AFRL's 11 Levels of Autonomy[72]

Level	Level Description
0	Remotely piloted vehicle
1	Execute pre-planned mission remotely
2	Changeable mission
3	Robust response to real time faults/events
4	Fault/event adaptive vehicle
5	Real time multi-vehicle coordination
6	Real time multi-vehicle cooperation
7	Battlespace knowledge
8	Battlespace single cognizance
9	Battlespace swarm cognizance
10	Fully autonomous

The AFRL spectrum describes autonomy at each stage of the OODA Loop. A small sampling of the chart shows its value:

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[69] Sholes, *supra* note 34, at 2–3.
[70] *Id.* at 2.
[71] *Id.*
[72] *Id.* at 3.

TABLE 3: Autonomy Spectrum and the OODA Loop[73]

Level	Observe	Orient	Decide	Act
0	Flight control sensing & on-board camera.	Telemetered data; remote pilot commands.	None. Off-board pilot.	Control by remote pilot.
5	Local sensors to detect external targets, fused with off-board data.	Group action diagnosis and resource management.	On-board trajectory planning; optimize for current & predicted conditions; collision avoidance.	Group accomplishment of tactical plan as externally assigned; air collision avoidance.
10	Cognizant of all within the battlespace.	Coordinates as necessary.	Capable of total independence.	Requires little guidance of any sort.

As this table shows, a system can effectively mix and match autonomy and automation. For example, a machine might operate at Level 10 at the *observe* stage and thus be cognizant of all objects in its environment. However, it might only achieve Level 5 at the *decide* stage, making it able to avoid collisions with objects in its environment but still in need of human assistance to realize more substantial objectives.[74]

D. Humans Control the Autonomy Spectrum

Technology constrains where a machine falls along the autonomy spectrum. Today, technology is not advanced enough to create complex machines capable of operating at

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[73] *Id.*
[74] *Id.* at 3–5.

high levels of autonomy along the entire OODA Loop. But as the technology progresses, it is critical to understand that engineers will still control a machine's level of autonomy through the machine's coding. A system's autonomy across the entire OODA Loop, and across all three attributes of autonomy — frequency of operator interaction, tolerance for environmental uncertainty, and level of assertiveness — is "entirely controllable by the customer and the development team."[75] Cultural norms, politics, and civilian and military demand, in additional to the state of the art, play an important role in the design of our machine systems.[76]

Engineers can control a machine's autonomy in several ways. First, the engineer can control *which functions* are automated as opposed to autonomous, perhaps by giving the machine the capability to perform only certain tasks autonomously. For example, an unmanned aerial drone may have autonomous control over its flight path — where and when it should fly. But, it might only be automated when it comes to firing a missile at an enemy — meaning that its human operator would retain absolute control of when and at whom to fire.

Second, the engineer can control *when* a machine is automated rather than autonomous. In other words, the engineer can allow the human operator to toggle between different levels of autonomy at different times, depending on the mission.[77] This allows "systems to adapt to users and contexts, especially in terms of dynamically tuning the

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[75] JONES & LEAMMUKDA, *supra* note 55, at 9.
[76] See *id.* at 287; *see also* BILL YENNE, BIRDS OF PREY: PREDATORS, REAPERS AND AMERICA'S NEWEST UAVS IN COMBAT 27 (2010). *See infra* Part V. Of course, particularly when it comes to militarized weapons systems, there may be great pressure to make a system as technologically advanced as possible. Just as it is dangerous to bring a knife to a gunfight, it would probably be ill-advised to send a Level 1 system into combat against an enemy fielding a Level 10 system.
[77] Parasuraman et al., *supra* note 35, at 289.

allocation of tasks between operators and machines."[78]

America's war drones today exhibit characteristics both of automation and autonomy, though they are primarily only automated systems. For example, the Global Hawk reconnaissance drone has the ability to take off and land unassisted.[79] The human operator need only press a button and direct it to take off.[80] However, the Global Hawk lacks the ability to autonomously direct its camera at areas it independently deems to be of interest.[81] For other functions, the human operator can choose among different levels of autonomy.[82] The Predator and Reaper drones each have three flight modes, which are selected by the human operator: manual flying (remote-control piloting), semi-autonomous monitored flight, and pre-programmed flight.[83]

The point is that even in these seemingly novel and advanced drone systems, humans control and can actively calibrate the level of autonomy. Tomorrow will bring a host of new technologies, many though not all of which we will want to embrace. Policymakers must understand that even as technology permits drones to achieve greater levels of autonomy, we can still control how autonomous we let our machines become. Unconstrained by legal and political constraints, what might tomorrow's autonomous drones look like? While no one can know for sure, it is still possible to compare tomorrow's projected technologies with the drones of yesterday and today.

III. DRONE WARFARE: YESTERDAY, TODAY, AND TOMORROW

Recent legal and policy debates about the use of drones in warfare focus on whether drones take humans "out of the

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[78] Coppin & Legras, *supra* note 35, at 593.
[79] SINGER, WIRED FOR WAR, *supra* note 5, at 36.
[80] *Id.*
[81] *Id*.
[82] Air Force Flight Plan, *supra* note 23, at 26–27.
[83] *Id.*

loop." This discussion is fraught with terms that are both loaded and vague. What does it mean for a human to be "inside," "outside," or "on" the loop? And why does it matter? Further confusing the issues, the debate over "drones" covers a tremendous range of technologies, including those deployed today and their even more sophisticated progeny of tomorrow.

It is difficult to structure a thoughtful debate and design an effective regulatory regime without first understanding the technology, including how it functions and how it differs from yesterday's weapons of war. Part II of this paper has begun to address that gap by providing a lens through which legal and policy analysts can understand how machines function and by offering bases upon which to compare different types of machine systems. To put detail behind that more abstract discussion, we now describe the drones of yesterday, today, and tomorrow, with an eye to demonstrating how tomorrow's drones will exhibit increasing levels of autonomy.

Before we proceed, we offer two notes of caution. First, drone technology is rapidly advancing, and much of the state of the art is classified and thus not available to the general public. Our discussion of current and future drone technologies is based on the latest publicly available information. Drone systems deployed by the United States military might exhibit greater levels of autonomy than is currently disclosed to the public and discussed herein.

Second, our discussion of drone technology focuses on combat and surveillance drones. To be sure, drones promise to be useful not only in waging war and catching criminals, but also in a range of civilian means, including search and rescue missions, healthcare, commercial, sporting, and leisure activities. Our discussion here is not meant to discount these possible uses of drones; they are, however, beyond the scope of this Article.

A. Yesterday's Drones

2001: A Space Odyssey, Stanley Kubrick's dystopian masterpiece, vividly portrays the advent of warfare. In the movie's famous opening sequence, early Man discovers that his tools may be used as weapons — and he promptly capitalizes on this discovery, taking over control of a competing group's watering hole by clubbing its leader to death. Warfare has been evolving ever since. Scholars even have a term for significant advances in warfare technology: they call these paradigm shifts "revolutions in military affairs," or RMAs for short.[84] One RMA happened when the English introduced longbow archers during the Middle Ages, ending the reign of horse-mounted knights. Another RMA came in the mid-fifteenth century, with the dawn of the gunpowder age. In all, historians estimate there have been at least ten RMAs since 1300.[85]

To understand today's warfare technology, one naturally compares it with the technologies that came before. It is necessary, though, to identify the relevant points of comparison. Comparing today's Predator drones with the clubs, arrows, and muskets of yesteryear is interesting but not very useful. Contrasting today's technologies with weapons that have exhibited some level of automation is far more helpful.

Basic autonomy is a relatively recent phenomenon, but automated machines have been used in warfare at least since the beginning of the twentieth century. Nikola Tesla mastered wireless communication in 1893.[86] Five years later, before a crowd at Madison Square Garden, Tesla demonstrated the ability to remotely control the movements of a motorboat.[87]

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[84] SINGER, WIRED FOR WAR, *supra* note 5, at 181.
[85] *Id.* at 182.
[86] *Id.* at 46.
[87] *Id.* at 46.

With advances in both wireless radio guidance and engine technology, remote-controlled warfare was underway.[88]

Some of the earliest drones were used as target practice for American fighter pilots during World War II. The most famous example was the "Dennymite," a radio controlled plane that was used by the U.S. military and was invented by Reginald Denny, a British World War I pilot turned Hollywood star.[89] The Germans also managed to weaponize remote-controlled machines during World War II. They deployed the land torpedo "Goliath," a remote-controlled car loaded with explosives that was driven into enemy tanks and bunkers.[90] They also developed the "Fritz," a drone-like bomb with wings. The Fritz would be dropped from a plane, and a "pilot" would guide the bomb into a target via remote control.[91] The Dennymite, Goliath, and Fritz were primitive technologies that required constant interaction with their human operator. Each lacked any ability to navigate the OODA Loop independently, and thus each falls squarely at Level 0 — "remotely piloted vehicle" — on the Air Force's 11-level autonomy spectrum.

Early automated drones were also used for surveillance and reconnaissance missions. For example, the Ryan Firebee II was a spy plane used during the Vietnam War and had a range of nearly 900 miles and a flight endurance of more than one hour.[92] Another reconnaissance drone was the "Lightning Bug," a remote controlled plane used extensively by the U.S. military in Southeast Asia between 1964 and 1975.[93] Both the Firebee and the Lightning Bug, like other drones of their generation, were "electro-optically guided, meaning that the

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[88] YENNE, *supra* note 76, at 9.
[89] SINGER, WIRED FOR WAR, *supra* note 5, at 49; YENNE, *supra* note 76, at 10.
[90] SINGER, WIRED FOR WAR, *supra* note 5, at 47.
[91] *Id.* at 48.
[92] YENNE, *supra* note 76, at 14.
[93] *Id.* at 15.

controller at a remote control station could watch their progress on television as though he was aboard."[94] While they represented a huge leap forward in military technology, they are primitive compared to today's and tomorrow's drones and likely belong at Level 0 on the Air Force's 11-level autonomy spectrum.

War drives demand for warfare technologies, and the Cold War was no exception. But the rise of computer technology shifted attention and money away from robotics, dampening both demand for and development of automated warfare technologies.[95] Those programs that did receive funding fared poorly. One noteworthy failure was the U.S. Army's ill-fated Aquila program, which was launched in 1979 with the goal of developing a remotely operated drone plane that would fly over enemy territory and conduct surveillance tasks.[96] In 1987, eight years and $1 billion dollars later, the program was cancelled with only a few primitive prototypes to show for the military's efforts.[97]

Although advances happened gradually, progress did occur. During the Gulf War, the U.S. military deployed the Pioneer drone, a remote-controlled reconnaissance drone that conducted both surveillance and battlefield damage assessments.[98] In a symbolic step forward, if not a technological one, a Pioneer drone became responsible for the first-ever surrender of human soldiers to an unmanned system when Iraqi soldiers surrendered to the Pioneer by waving white bedsheets and undershirts at the mechanized soldier in the sky.[99]

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[94] *Id.*
[95] *Id.* at 53.
[96] *Id.* at 55.
[97] *Id.*
[98] *Id.* at 57; YENNE, *supra* note 76, at 27.
[99] SINGER, WIRED FOR WAR, *supra* note 5, at 57; YENNE, *supra* note 76, at 27.

The rudimentary state of guidance technology was among the largest constraints on the development of early remote-operated weapons systems. Guidance capability — the ability to make an object follow a moving target or deviate from its course as necessary — is what separates many modern unmanned weapons from a simple bullet.[100] A significant step toward precision bombing came in 1920, when Carl Norden took advantage of the newly developed computer technology to invent the Norden bombsight.[101] The Norden's computer improved an aerial bomber's accuracy by automatically launching a missile at the right time to hit, or at least come near to hitting, the desired target.[102] When Paul Tibbets dropped "Little Boy" from the *Enola Gay* onto the city of Hiroshima on August 6, 1945, a Norden bombsight was used ensure the uranium bomb was dropped at the appropriate moment.[103]

Precision targeting took a huge leap forward with perhaps the twentieth century's most significant development in unmanned war technology, the invention of laser-guided bombs and cruise missiles. Laser-guided bombs are not actively steered and driven by human operators.[104] Rather, the human operator illuminates the target using a laser, and the bomb uses the laser guidance to steer into the target.[105] With early models, the human had to continuously keep the laser on the target until the bomb landed. Later technology, however, allowed the human to exit the scene while the bomb completed the mission on its own.[106]

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[100] YENNE, *supra* note 76, at 9.
[101] SINGER, WIRED FOR WAR, *supra* note 5, at 50.
[102] Peter W. Singer, *In the Loop? Armed Robots and the Future of War*, BROOKINGS INSTITUTION (Jan. 28, 2009), *available at* http://www.brookings.edu/articles/2009/0128_robots_singer.aspx [hereafter Singer, *In the Loop?*]
[103] SINGER, WIRED FOR WAR, *supra* note 5, at 51.
[104] *Id.* at 57.
[105] *Id.*
[106] *Id.*

This was something new: a weapon that could follow a target and did not need to be constantly guided and steered by a human operator. Nonetheless, these laser-guided bombs were still quite primitive, especially if evaluated on the autonomy scale. The systems lacked decision-making ability and exhibited only the limited capacity to execute a pre-programmed command to follow and crash into a specific target, placing them at most at Level 1 on the Air Force's 11-level autonomy spectrum. Moreover, laser-guided bombs had the critical weakness of poor functioning in bad weather.[107] Dust, haze, or smoke could make the bomb's laser guidance capabilities useless.[108]

Cruise missiles are more sophisticated weapons than laser-guided bombs, because they fly themselves using preset coordinate or recognition software.[109] The first cruise missiles, including the pioneering German Fiesler Fi.103, were introduced during World War II.[110] Early cruise missiles lacked precision guidance, meaning their ability to hit a specified enemy target was quite limited.[111] Technological advances eventually culminated in the Tomahawk missile, which wreaked havoc in the Middle East during the Gulf War.[112]

Yet when we study the Tomahawk missile through the lens of the OODA Loop and autonomy spectrum, its limitations become apparent. A Tomahawk's target must be set *before* the missile takes off.[113] The Tomahawk could not be programmed to attack a particular target midflight and "[i]t could not react to change" in its environment.[114] Furthermore, while the ability to instruct a Tomahawk to embed itself at a

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[107] *Id.*
[108] *Id.*
[109] *Id.*
[110] YENNE, *supra* note 76, at 12.
[111] *Id.*
[112] SINGER, WIRED FOR WAR, *supra* note 5, at 57.
[113] *Id.* at 58.
[114] *Id.*

particular site diminishes the need for constant human guidance while in flight, the missile had to travel over terrain that has already been mapped out and preprogrammed into its computer memory.[115] While the Tomahawk's reliance on its human operator was minimal once it was fired, its ability to dynamically manage environmental uncertainty was very limited.[116]

The history presented here is necessarily brief, but these vignettes offer a few important lessons that apply broadly to early forays into mechanized warfare. The most important point is that while these technologies do exhibit some characteristics of automation, they have almost none of the characteristics of autonomy discussed in Part II. They are all at Level 0 or Level 1 on the Air Force autonomy spectrum. Most of the technologies were remote controlled, including the Goliaths and Fritzes of World War II and the Pioneer drones of the Gulf War. This means they required constant interaction with the human operator, so one of three attributes of autonomy was wholly missing. Moreover, if the communications link failed, the systems were often rendered useless. Indeed, a number of reconnaissance drones crashed over North Vietnam during the Vietnam War when the data link to the human operators cut out.[117]

Those early machines that did not require frequent interaction with their human operators generally lacked the ability to navigate uncertain environments and had virtually no mission assertiveness. The Tomahawk missile is a good example, for it could only travel over known terrain and was unable to change targets or to stray into unknown lands. These technological constraints limited the machines' functionality. Most early unmanned weapons systems were essentially either target drones created to be destroyed in practice, or missiles designed to destroy enemy facilities.

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[115] *Id.* at 57.
[116] *Id.*
[117] YENNE, *supra* note 76, at 23.

These systems were automated weapons, to be sure, but they had virtually no ability to navigate the OODA Loop with anything resembling autonomy.

B. Today's Drones

As the discussion above shows, the U.S. military has a rich history of using unmanned remote-operated vehicles during the Twentieth Century. But the advent of the post-September 11, 2011 global War on Terror has vastly expanded the use of military drones.[118] Several factors drove this trend. By 2011, technology had improved to the point where the widespread use of drones became both feasible and attractive. While the early drone technology described above was hampered by technical challenges, including inadequate communications equipment and a limited ability to integrate an airplane's flight and targeting systems,[119] new technologies have permitted drones to become more effective. GPS technology in particular has facilitated our ability to maneuver and guide unmanned drones with precision.[120]

Political and cultural factors have also driven the push towards the use of drone technology in military engagements abroad. Terrorists are unlike the conventional enemies of World War I and II in important respects. They are not confined to a particular battle space, driving demand for 24/7 global surveillance that can be more effectively accomplished with a drone than with a human pilot.[121] Targeted drone

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[118] SINGER, WIRED FOR WAR, *supra* note 5, at 61 (quoting Larry Dickerson, who wrote that "[p]rior to 9/11, the size of the unmanned vehicle market had been growing, but at an almost glacial place").
[119] YENNE, *supra* note 76, at 23.
[120] SINGER, WIRED FOR WAR, *supra* note 5, at 58.
[121] See Gary E. Marchant et al., *International Governance of Autonomous Military Robots*, 12 COLUM. SCI. & TECH. L. REV. 272, 275 (2011) (arguing that drones allow for force multiplication and the expansion of the battlespace, perhaps fewer humans to conduct surveillance over a larger terrain).

killings have also proved to be a relatively efficient way to confront terrorists that hide among civilian populations.[122] Diminished political tolerance for military casualties has also made drones more attractive, since they keeps soldiers farther from the battlefield, preserving the lives of American servicemen.[123] The weaponry itself is also improved; the Predator drone's smaller Hellfire missiles probably cause less collateral damage and loss of civilian life than larger alternatives launched from further away.[124] Increased judicial scrutiny of detention practices may have also increased the appeal of targeted drone killings.[125] Over time, the military has lowered its cultural opposition to drones, particularly its resistance to the notion that a plane should be piloted by a

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[122] Jonathan Ulrich, *The Gloves Were Never on: Defining the President's Authority to Order Targeted Killing in the War Against Terrorism*, 45 VA. J. INT'L L. 1029, 1053 (2005). Drones have much greater endurance ability than humans, so they can patrol a given area for much longer without needing rest and without mental fatigue. See SINGER, WIRED FOR WAR, *supra* note 5, at 36.

[123] Report of the Special Rapporteur on extrajudicial, summary or arbitrary executions, Philip Alston, Addendum, Study on Targeted Killings, U.N. Doc. A/HRC/14/24/Add.6, at 9 (May 28, 2010) ("The appeal of armed drones is clear: especially in hostile terrain, they permit targeted killings at little to no risk to the State personnel carrying them out, and they can be operated remotely from the home State.").

[124] Jane Mayer, *The Predator War: What are the risks of the C.I.A.'s covert drone program?*, NEW YORKER Oct. 26, 2009 ("Predator drones, with their superior surveillance abilities, have a better track record for accuracy than fighter jets, according to intelligence officials. Also, the drone's smaller Hellfire missiles are said to cause far less collateral damage.").

[125] GABRIELLA BLUM & PHILIP B. HEYMANN, LAWS, OUTLAWS, AND TERRORISTS: LESSONS FROM THE WAR ON TERRORISM 88 (2010) ("[T]he killing of a terrorist often proves a simpler operation than protracted legal battles over detention, trial, extradition, and release. The more complicated detention has become, the more attractive the option of targeted killing seems to be.").

computer rather than a human pilot.[126] And of course, there are also cost concerns: in some cases, drones may be significantly cheaper to operate than manned vehicles.[127]

Many of these same trends will spur the use of drones at home, too. As the United States winds down its military actions abroad, it will be bringing home not only brave men and women, but also many of the 1,800 drone aircraft that the military owns.[128] Many policymakers want drones to be used domestically in law enforcement efforts and Congress has obliged, instructing the Federal Aviation Administration (FAA) to unshackle restrictions on domestic use of drones, first for law enforcement purposes, and by 2015 for commercial purposes too.[129] For states facing budget crises, drones promise to be low-cost and highly efficient means of law enforcement. Drones are already deployed along the Mexican-American border, to monitor for illegal entrants into this country.[130] They have already been used for more routine law enforcement duties like assisting with arrests, and could even be used for commercial purposes, like assisting tuna fishermen in their search for fish.[131]

These drones are not an undifferentiated mass. The machines come in many different sizes and shapes. Any regulatory regime of either domestic or wartime drones must take into account the spectrum of drone technology that exists today, and that will exist tomorrow.

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[126] YENNE, *supra* note 76, at 27.
[127] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 114.
[128] Sarah Childress, The Military's Plan for Drones at Home, PBS FRONTLINE (June 19, 2012), *available at* http://www.pbs.org/wgbh/pages/frontline/foreign-affairs-defense/the-militarys-plans-for-drones-at-home/.
[129] Wingfield & Sengupta, *supra* note 4. As Nick Paumgarten points out in *The New Yorker*, "[a]ir safety, not privacy or due process, is the F.A.A.'s chief concern, and in that regard alone it has its hands full." Paumgarten, *supra* note 3, at 48.
[130] Booth, *supra* note 2.
[131] Paumgarten, *supra* note 3, at 46, 58.

1. Aerial Drones

Unmanned aerial vehicles are the most well-known and widely deployed segment of the U.S. military's unmanned weapons portfolio. The queen of America's aerial drone program is the Predator, a 27-foot, 1,130-pound airplane that can spend 24 hours in the air at a time.[132] The Predator boasts incredibly sophisticated surveillance capabilities. It has the ability to loiter over a target for long periods,[133] read a license plate from two miles away,[134] and monitor terrain below during day or night, through fog, cloud cover, or gloom of night.[135]

The Predator was originally designed to conduct surveillance and was first deployed on reconnaissance missions over the Balkans in 1995 and 1996.[136] After 9/11, the drone was outfitted with a payload of laser-guided Hellfire missiles, turning the Predator into a deadly war machine.[137] The Predator's surveillance capabilities are still critical, however, and this bird has been used to provide continuous, useful real-time surveillance to soldiers on the ground.[138] While there is no human in the cockpit, each Predator mission does require significant dedication of human manpower. A Predator's crew consists of one pilot and two sensor operators, but it takes a total of 82 people, including technical support staff, to fly it.[139]

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[132] Robert Valdes, *How the Predator UAV Works*, HOW STUFF WORKS (Apr. 1, 2004), *available at* www.science.howstuffworks.com/predator.htm (last visited Apr. 20, 2012).
[133] YENNE, *supra* note 76, at 48.
[134] *Id.*
[135] *Id.* at 32–33.
[136] *Id.* at 39.
[137] *Id.* at 43–45.
[138] *Id.* at 69.
[139] Valdes, *supra* note 132.

In many ways, the Reaper drone is a souped-up version of the Predator. The Reaper can fly twice as fast and at double the altitude of the Predator while carrying a 3,750-pound payload, a nearly ten-fold increase over the Predator's 450-pound payload weight limit.[140] Instead of the Hellfire, the Reaper often carries the Maverick missile, a larger bomb capable of more "heavy duty" tasks like busting tanks.[141] The Reaper lacks the Predator's ability to loiter, however, and its flight endurance period of approximately 18 hours is slightly shorter than the Predator's 22-hour limit.[142] If two 1,000-pound external fuel tanks are added to the Reaper, however, its endurance jumps to 42 hours.[143] The Reaper's extra capabilities come at a higher cost of $53.5 million per unit, compared to the Predator's $20 million per-unit price tag.[144]

While the Predator and Reaper drones have more advanced surveillance and attack capabilities than their predecessors, in many ways these drones are still remote-operated planes that operate at the lower end of the autonomy spectrum. As one commentator notes, "[a]s an aircraft, the Predator UAV is little more than a super-fancy remote-controlled plane."[145] Both the Predator and Reaper can be

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[140] Air Force Flight Plan, *supra* note 23, at 26–27; United States Air Force, *MQ-1B Predator*, Jan. 5, 2012, *available at* http://www.af.mil/information/factsheets/factsheet.asp?id=122; United States Air Force, *MQ-9 Reaper*, Jan. 5, 2012, *available at* http://www.af.mil/information/factsheets/factsheet.asp?id=6405.

[141] YENNE, *supra* note 76, at 79.

[142] Air Force Flight Plan, *supra* note 23, at 26–27.

[143] YENNE, *supra* note 76, at 79.

[144] United States Air Force, *MQ-1B Predator*, *supra* note 140; United States Air Force, *MQ-9 Reaper*, *supra* note 140.

[145] Valdes, *supra* note 132. For a detailed account of one Predator pilot's experience during the Iraq and Afghanistan conflicts, see MATT J. MARTIN & CHARLES W. SASSER, PREDATOR: THE REMOTE-CONTROL AIR WAR OVER IRAQ & AFGHANISTAN: A PILOT'S STORY (2010).

flown on one of three modes, as was mentioned above, ranging from remote-control flying, semi-autonomous monitored flight, and pre-programmed flight.[146] Each of these modes, however, requires frequent human interaction. The birds are unable to suggest sophisticated actions to human operators or decide independently how to act.

The military also deploys surveillance drones that, unlike the Predator and Reaper drones, do not carry a weaponized payload. At the larger end is the Global Hawk drone, a high-altitude, long-range reconnaissance drone with a 28-hour endurance limit and the capability to conduct observations and collect information from 65,000 feet up.[147] The Global Hawk has the ability to watch the ground below day and night, and through most types of weather.[148] The Global Hawk may take off and land almost entirely unassisted — "the operator just clicks to tell it to taxi and take off, and the drone flies off on its own."[149] The 30,000 pound drone does "requires a small army of people to operate and service each plane."[150] The Global Hawk has begun to climb up the autonomy spectrum, and might be placed at Level 1 or Level 2 on the Air Force's autonomy spectrum.

The military also uses a number of smaller hand-launched surveillance drones. The Raven, for example, is a hand-launched surveillance drone with a range of seven to ten miles that can either be manually flown or programmed via GPS to follow a pre-determined flight path.[151] To launch the three-foot long Raven, a soldier simply picks up the device and heaves it in the air — there is little more takeoff technology

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[146] Air Force Flight Plan, *supra* note 23, at 26–27.
[147] *Id.* at 27.
[148] Gayle Putrich, *Next generation of Global Hawks ready to roll*, FLIGHT INT'L (Aug. 16, 2010), *available at* http://www.flightglobal.com/news/articles/next-generation-of-global-hawks-ready-to-roll-346116.
[149] SINGER, WIRED FOR WAR, *supra* note 5, at 36.
[150] Paumgarten, *supra* note 3, at 53.
[151] Air Force Flight Plan, *supra* note 23, at 26.

than a paper airplane. But the Raven does have some degree of autonomy in its flight path. Its human operator can pilot the Raven via remote control,[152] but it can also input its flight path into a computer and have the Raven do the rest.[153] The Raven, which can fly for 90 minutes, can be programmed "to follow a target, or to loiter, and, if it loses its link to the ground-control unit, to return home or to climb higher," and the drone has the capability to adjust to the wind all by itself.[154]

The Wasp III, the Raven's mechanical cousin, is a hand-launched surveillance drone with a range of up to three miles that can either be manually flown or programmed via GPS to follow a predetermined flight path.[155] (Indeed, many drones are operated with "joysticks that resemble video-game controls."[156] Some successful drone pilots got their start in their parents' basement playing Xbox and Playstation.[157]) Although these drones operate at the lower ends of the Air Force's autonomy spectrum, they do exhibit some of the more bona fide qualities of autonomy.

2. Land-bound drones

The press and public debates have focused on aerial drones, but not all unmanned drones are airborne. The PackBot and the SWORDS drone are two leading examples of land-based drones. The PackBot, deployed by the military in Iraq and Afghanistan to detect improved explosive devices ("IEDs"), is the size of a lawnmower and, at 42 pounds,

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152 SINGER, WIRED FOR WAR, *supra* note 5, at 37.
153 Paumgarten, *supra* note 3, at 54.
154 *Id.*
155 Air Force Flight Plan, *supra* note 23, at 25.
156 Mayer, *supra* note 124.
157 Griffin McElroy, *Soldier became ace drone pilot by training on video games*, JOYSTIQ (Feb. 7, 2009), *available at* http://www.joystiq.com/2009/02/07/soldier-became-ace-drone-pilot-by-training-on-video-games/.

weighs about as much as a three-year-old child.[158] PackBot is normally remote-controlled by a nearby American service member, though the drone does have a limited capability to drive itself independent of a human operator.[159] The PackBot can perform many functions. As if outfitted by James Bond's Q, PackBot carries with it a mine detector, chemical and biological weapons sensor, and auxiliary power packs.

But while James Bond's human handlers could never quite control him, PackBot heavily relies on its human operators to operate and to switch between and deploy the different tools.[160] While PackBot is equipped with a camera in order to peer at possible IEDs, it simply transmits that information back to its controlling soldier and does not actually interpret the visual information itself.[161] The PackBot lacks the capability to independently observe the objects in its environment and decide for itself which sensor to deploy at a given time. Instead, the bot depends on regular interaction with its operator to fulfill its tasks. If the communications link cuts out, the bot is unable to continue its rounds and search the area for IEDs. The PackBot ranks at the low end of the Air Force's autonomy spectrum, probably no higher than Level 1.

The SWORDS drone has a fearsome name, but its moniker may yet be understatement: SWORDS is a robot equipped with a mounting that can carry almost any weapon under 300 pounds, including a machine gun, grenade launcher, and antitank rocket launcher.[162] On the autonomy spectrum, however, SWORDS is in many ways even more primitive than PackBot. The SWORDS drone must always be remote controlled and the human operator is responsible for loading its gun, as well as for aiming, firing, and reloading.[163]

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[158] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 22.
[159] *Id.*
[160] *Id.*
[161] *Id.*
[162] *Id.* at 30.
[163] *Id.*

SWORDS is an archetypical automated but non-autonomous robot. It replaces human functions (lock, load, and fire) but does not supplant human decision-making.[164] SWORDS probably belongs at Level 0 or 1 on the Air Force's autonomy spectrum.

3. An automated, non-autonomous fleet

Technical problems still hamper America's drones. The communications links between drones and their remote pilots are especially unreliable and "regularly cut out, forcing the robotic aircraft into automatic holding patterns."[165] Today's drones have low levels of assertiveness, one of the critical attributes of autonomy, for they have little ability to complete a mission without close human direction. Frequent operator interaction is vital to complete and close the OODA Loop. Indeed, the primary technology advancement of the Predator and Reaper drones is *not* their autonomy or independence from humans, but rather simply that these drones are able to execute missions "without ever exposing the pilot to the hostile environment."[166] Thus, these drones are useful because they *replace* human actions — in other words, because they are highly *automated* machines. Predators, Reapers, and their mechanical kin differ from earlier versions of drones not in terms of increased autonomy, but rather because they are better automated.

Few of the military's weapons systems outsource to the machine any decision-making authority over when and at whom to shoot. There are some notable exceptions, such as Counter Rocket Artillery Mortar (CRAM) technology, an air

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[164] *Id.*
[165] Noah Schachtman, *Report: U.S. Drone Goes Down Over Pakistan. Again.*, WIRED DANGER ROOM BLOG, Jan. 25, 2010, 11:02AM, http://www.wired.com/dangerroom/2010/01/us-drone-goes-down-over-pakistan-again/.
[166] Valdes, *supra* note 132.

defense technology that "automatically tracks and shoots down any missiles that have gotten past all other defenses and are to quick for humans to react to."[167] Dubbed "R2-D2," the technology is not without flaws. The system once locked in upon and prepared to shoot down an American helicopter over Baghdad, nearly blowing up the plane and killing American soldiers.[168]

The Aegis sea defense system is another example of the benefits, and potentially dire costs, of contemporary machines programmed to kill. The Aegis has four modes, ranging from semiautomatic, in which the human controls the system and decides when and what to shoot, to "casualty," where the system is authorized to shoot on its own in order to keep the ship safe.[169] One risk associated with this system is that even in the less-autonomous modes, where a human retains a veto over the system's decisions, the humans will trust the machines better than their own judgment. This resulted in tragedy in 1988, when an Aegis system aboard the U.S.S. Vincennes shot down a civilian airliner it mistook for an Iranian fighter jet in the Persian Gulf.[170] Even though the Aegis system's human operators had a veto over the decision to shoot, they trusted the Aegis system more completely than they trusted themselves and allowed the machine to shoot.[171] The story illustrates the limitations of engineering in a different and painful way, for it shows that the operator's availability cannot address all the moral and legal problems posed by automated and autonomous machines.

Today, America's drone fleet makes the military more potent than it has ever been before. The drones permit more continuous surveillance of enemies and more accurate

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[167] SINGER, WIRED FOR WAR, *supra* note 5, at 38.
[168] *Id.*
[169] *Id.* at 124.
[170] *Id.* at 124 –25.
[171] Harris, *supra* note 9, at 10; SINGER, WIRED FOR WAR, *supra* note 5, at 125.

targeting at less financial cost, and less cost to soldiers' lives. These drones are more effective than their predecessors, and they are deployed on a previously unprecedented scale. But despite these incredible advances, the drones are still primarily automated, non-autonomous systems. Virtually all presently operative drones are at Levels 0, 1, or 2 on the autonomy spectrum.

C. Tomorrow's Drones

Tomorrow's drones will exhibit greater autonomy along all four stages of the OODA Loop. They will require less human interaction, they will navigate greater levels of environmental uncertainty, and they will enjoy higher levels of mission assertiveness. The military predicts that these increasingly autonomous machines will be eventually be fully integrated into the fighting forces.[172] By 2025, the American armed forces are expected to be "largely robotic."[173] "The robots you are seeing here today, I like to think of as the Model T," a robotics executive said at a 2007 demonstration of robot prototypes.[174] "We are seeing the very first stages of this technology."[175]

Reliance on drones will continue to grow, along with the appetite for drones able to operate independent of human control. Machine systems dependent on human commands are vulnerable to enemy communications sabotage; as a result, systems able to continue the missions even without contact and direction from an operator are especially valuable.[176] Some systems deployed in combat or defensive positions must be able to react in circumstances that do not permit time for a

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[172] Air Force Flight Plan, *supra* note 23, at 48.
[173] SINGER, WIRED FOR WAR, *supra* note 5, at 133.
[174] *Id.* at 110.
[175] *Id.*
[176] Singer, *In the Loop?*, *supra* note 102.

human to give command.[177] Finally, as the technology improves, drones will simply become better at executing a greater number of combat and surveillance tasks than humans.[178] As one commentator noted dryly: "They don't get hungry. They're not afraid. They don't forget their orders. They don't care if the guy next to them has just been shot. Will they do a better job than humans? Yes."[179]

The military is following Boyd's advice, albeit not necessarily in a way that he would have foreseen: the United States is developing autonomous systems that can cycle through the OODA Loop better and faster than our adversaries. "One of the most important elements to consider with this battlefield," the Air Force has observed, "is the potential for UAS [unmanned aerial systems] to rapidly compress the observe, orient, decide, and act (OODA) loop. Future UAS able to perceive the situation and act independently with limited or little human input will greatly shorten decision time."[180] Increasingly, the Air Force predicts, "humans will not longer be 'in the loop' but rather 'on the loop' — monitoring the execution of certain decisions."[181]

The next generation of drones will be able to take off and land without any human interaction.[182] The Phantom Eye, now a prototype, recently completed a twenty-eight minute-long autonomous flight, taking off, flying, and landing all on its own — and its creators hope to stretch that flight length to four days.[183] In the future, drones may be able to perform one

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[177] *Id.*
[178] SINGER, WIRED FOR WAR, *supra* note 5, at 63 (quoting Gordon Johnson of the Pentagon's Joint Forces Command).
[179] *Id.*
[180] Air Force Flight Plan, *supra* note 23, at 16.
[181] *Id.* at 41.
[182] *Id.* at 39.
[183] Boeing Company, Boeing Phantom Eye Completes First Autonomous Flight (June 4, 2012), *available at* http://boeing.mediaroom.com/index.php?s=43&item=2276.

of the most difficult flight tasks — landing on an aircraft carrier — without any human control.[184]

Drones will also have the capability to stay aloft for much longer periods of time. The Defense Advanced Research Projects Agency (DARPA), a Department of Defense agency that funds research of new technologies, has invested in the development of drones that can stay aloft for up to five years.[185] Drones will also be able to conduct surveillance without the need for a human operator actively steering a camera to areas of interest. The next generation of Reaper drone, for instance, are expected to have the capability to not only "recognize and categorize humans and human-made objects" that it encounters, but also to "make sense of changes it is watching, such as being able to interpret and retrace footprints or even lawn mower tracks."[186]

The goal is to advance drone technology to the point where machines are able "to make combat decisions and act within legal and policy constraints without necessarily requiring human input."[187] Machine systems will be fully integrated into the armed forces, with commanders able to refine a system's level of autonomy by mission, just as they can now similarly vary a human soldier's rules of engagement.[188] These drones will increasingly take to the sea and ground, both of which far more complex and difficult environments to navigate than the air. One such ground robot is the Gladiator, a well-armed combat robot that will be able to operate on semi-autonomous and fully autonomous modes.[189] In the water, researchers are developing the Spartan Scout, now a prototype, that is designed to be launched into the sea and travel on its own for up to two days, carrying out

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[184] Hennigan, *supra* note 20.
[185] SINGER, *supra* note 41, at 117.
[186] *Id.* at 116.
[187] Air Force Flight Plan, *supra* note 23, at 41.
[188] *Id.*
[189] SINGER, WIRED FOR WAR, *supra* note 5, at 111.

surveillance missions, protectively patrolling harbors, and inspecting any suspicious ships it encounters.[190]

One of the most fascinating and novel trends is towards micro-drones and nano-drones, some bio-mechanical and as tiny as the width of a human hair.[191] These drones are expected to work together in large swarms, communicating with each other and coordinating their activities. Publicly available military sources suggest these nano-drones portend a paradigm shift, with the "[d]evelopment of the nano/micro class" creating "capabilities never before realized."[192]

According to one observer, nano-drones add to the push beyond mere automation because their tiny designs and numerosity "actually mandate that the systems will have to have high autonomy, carrying out their missions without human controllers."[193] Significant autonomy is necessary because the drones are too numerous for each to have an individual human controller; moreover, flying the micro machines will actually make most human operators nauseous.[194] And the very effectiveness of these drones comes from their ability to communicate with each other and coordinate their actions more effectively and rapidly than a group of human operators could possibly do.[195]

One risk associated with these nano-drones is that because they are not fully controllable by humans, they may not go exactly where the operator wants them to go, or do exactly what she wants them to do.[196] The human controller is responsible for directing the swarm and will have the ability to monitor the swarming unit, but his ability to control their individual actions may be quite limited.[197]

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[190] *Id.* at 115.
[191] *Id.* at 118.
[192] Air Force Flight Plan, *supra* note 23, at 36.
[193] SINGER, WIRED FOR WAR, *supra* note 5, at 119.
[194] *Id.*
[195] *Id.*
[196] *Id.* at 235.
[197] See Air Force Flight Plan, *supra* note 23, at 34.

D. The Paradigm Shift Yet to Come

For lawyers, policymakers, and the public, today's drones are revolutionary different from those of yesteryear. In many ways, they are correct. Contemporary drones keep their human operators farther from the battlefield than ever before. During World War II, for instance, the German "Fritz" had to be dropped from a human-operated plane above the battlefield.[198] Today, American pilots fly planes around the world from a relatively safe perch, often in Nevada, away from the battlefield.[199] Today's drones also have much greater endurance than their human counterparts. A surveillance drone can fly for hours, and soon for days, at a time; a combat drone can stalk prey for long periods, awaiting the right moment to strike.[200] Further, drones today are deployed on a wholly new scale. The cost of technology is low enough, and the cost of human forces high enough, that drones may soon outnumber human soldiers.

But for engineers, today's machines are actually not so different from the automated systems of the past century. Today's drones remain primarily at Levels 0 or 1 of the autonomy spectrum, often operated by remote control.[201] The human pilot remains, albeit not in the cockpit. To be sure, today's machines are far more effective automated robots than yesterday's automated robots. But they are still automated, not autonomous.

Although engineers and policymakers may disagree about whether today's drones truly are different, the systems of tomorrow will unite the two camps. The race is on to develop autonomous systems that can complete the OODA Loop better

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[198] SINGER, WIRED FOR WAR, *supra* note 5, at 48.
[199] MARTIN & SASSER, *supra* note 145, at 2.
[200] *See supra* Part III.B.1.
[201] SINGER, WIRED FOR WAR, *supra* note 5, at 36; YENNE, *supra* note 76, at 40, 75.

and faster than our rivals.[202] The systems currently being developed on the floors of labs and in the minds of inventors may prove to be truly *new* technologies. These machines will climb higher on the autonomy scale — through Levels 4, 5, 6, and beyond — and eventually be able to complete the OODA Loop with complete independence from human operators. Truly autonomous drones may have capabilities not before seen. If we struggle with the implications of today's technology, the conversations about tomorrow's will be still more fraught.

Human intervention will still affect tomorrow's advanced systems, but at an earlier stage in what could be loosely dubbed a machine's "lifecycle." Engineers will still be able to program how systems process the information around them and, more importantly, to control the factors that machines consider during the decision-making processes.[203] As pressure intensifies to deploy systems able to complete the loop faster than human synapses permit, hotly debated law and policy questions, including whether drones are capable of complying with international law (particularly *jus in bello* and *jus ad bello* requirements),[204] must increasingly be addressed at the

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[202] *See* Air Force Flight Plan, *supra* note 23, at 16.

[203] While a discussion of the effect of increasingly autonomous technologies on supply chain security needs and the heightened potential for havoc to be wrought by insider threats is beyond the scope of this paper, these issues are grave, urgent, and clearly implicated by the shift towards greater autonomy.

[204] *See, e.g.*, Ryan J. Vogel, *Drone Warfare and the Law of Armed Conflict*, 39 DENV. J. INT'L L. & POL'Y 138 (2010); Chris Jenks, *Law from Above: Unmanned Aerial Systems, Use of Force, and the Law of Armed Conflict*, 85 N.D. L. REV. 649, 671 (2009); Richard Murphy & Afsheen John Radsan, *Due Process and Targeted Killing of Terrorists*, 31 CARDOZO L. REV. 405 (2009); Kenneth Anderson, *Targeted Killing in US Counterterrorism Strategy and Law,* SERIES ON COUNTERTERRORISM AND AMERICAN STATUTORY LAW, at 34 (May 2009); Mary Ellen O'Connell, *To Kill or Capture Suspects in the Global War on Terror*, 35 CASE W. RES. J. INT'L L. 325 (2003).

design stage. While a detailed discussion of these laws of war and their application to machine warfare is beyond the scope of this paper,[205] the point remains. As the machines evolve, so too will the meaning of having a human "in the loop."

IV. LAW AND ETHICS FOR AUTONOMOUS SYSTEMS

Today, technology constrains our ability to make systems truly autonomous. This will not always be so. As technology continues to advance, legal, cultural, and political considerations will increasingly function as the primary limitations upon our weapons systems. Problems posed by tomorrow's drones should be discussed today, while the technology is still in a relatively nascent stage and the opportunity remains to control its development.[206] The embryonic state of the art offers policy makers a unique opportunity to think creatively and proactively about these systems' future development.[207]

Legal, political, and cultural considerations do impose real boundaries.[208] For example, plans to construct a nuclear-powered drone able to stay aloft for years at a time were

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[205] For thoughtful commentary, see Kenneth Anderson, *Efficiency in Bello and ad Bellum: Targeted Killing Through Drone Warfare*, SSRN (Sept. 23, 2011), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1812124; *see also* Jenks, *supra* note 204, at 671.

[206] See *supra* Parts III-IV.

[207] *Cf.* Ronald C. Arkin et al., *Moral Decision Making in Autonomous Systems: Enforcement, Moral Emotions, Dignity, Trust, and Deception*, Proceedings of the IEEE Vol. 100, No. 3., at 1 (Mar. 2012) [hereafter *Moral Decision Making in Autonomous Systems*], *available at* http://smartech.gatech.edu/jspui/bitstream/1853/40769/1/IEEE-ethicsv17.pdf.

[208] Nick Fielding, *U.S. Draws Up Plans for Nuclear Drones*, THE GUARDIAN (Apr. 2, 2012), *available at* http://www.guardian.co.uk/world/2012/apr/02/us-plans-nuclear-drones.

recently shut down over concerns about nuclear fallout from a drone crash and fear that terrorist groups might obtain the technology.[209] Lawyers and policymakers should reject technological determinism, which denies the ability of law and culture to impact system development.

Drones raise a thicket of difficult policy questions, as the American public is beginning to realize. Domestically, commentators on both the right and left have worried that a fleet of potentially 'round-the-clock aerial drones will erode our privacy and transform America into an Orwellian dystopia.[210] And on the combat front, there are concerns that drones may make warfare too "easy" or "low cost," lowering the barriers to military action and encouraging us to put more and more enemies on kill lists.[211]

These concerns have launched a rich debate over how, if at all, the United States ought to constrain its deployment of drone technology. For example, Senator Rand Paul recently introduced a bill that would prohibit the domestic use of

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[209] *Id.*

[210] See Wingfield & Sengupta, *supra* note 4 (noting that civil libertarians including the American Civil Liberties Union are concerned that domestic use of drones will inaugurate "routine aerial surveillance of American life"). *See also* Jay Stanley & Catherine Crump, *Protecting Privacy From Aerial Surveillance: Recommendations for Government Use of Drone Aircraft,* AMERICAN CIVIL LIBERTIES UNION (Dec. 2011), *available at* http://www.aclu.org/files/assets/protectingprivacyfromaerialsurveillance.pdf.

[211] See Peter Singer, *Do Drones Undermine Democracy?*, N.Y. TIMES (Jan. 21, 2012), *available at* http://www.nytimes.com/2012/01/22/opinion/sunday/do-drones-undermine-democracy.html ("I do not condemn [drone] strikes; I support most of them. What troubles me, though, is how a new technology is short-circuiting the decision-making process for what used to be the most important choice a democracy could make. Something that would have previously been viewed as a war is simply not being treated like a war.").

drones by the government unless it first obtains a warrant or demonstrates that exigent circumstances exist.[212] The International Association of Chiefs of Police has provided a series of guidelines for the domestic use of drones.[213] Its recommendations include retaining close human control over where drones fly, ensuring that drone aircraft are highly visible to the public, and strongly discouraging the weaponization of domestic drones.[214]

A. Using OODA to Regulate Drones.

Our discussion of autonomy and the OODA Loop suggests ways to structure regulatory regimes, for it allows us to identify ways to design legal controls that target specific concerns. The current debate over whether humans are "in the loop" or "out of the loop" has an all-or-nothing feel to it: humans are either in or out. This frame is unhelpful because it is too simplistic. As this paper has shown, a machine does not traverse a single loop; instead, it will work through the OODA Loop dozens or even thousands of times during each mission. Each loop might be addressed to a different task — whether to move left around a boulder, shoot a missile, or take some other action.[215] Humans can calibrate how "wide" the loop may be — how autonomously a machine functions — and the level of autonomy can vary across each stage of the cycle.[216]

If we do want to regulate the technologies, adopting a more nuanced view of machines and legislating accordingly

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[212] Rand Paul, *Don't let drones invade our privacy*, CNN (June 15, 2012), *available at* http://www.cnn.com/2012/06/14/opinion/rand-paul-drones/index.html.

[213] Aviation Committee, International Association of Chiefs of Police, Recommended Guidelines for the use of Unmanned Aircraft (Aug. 13, 2012), *available at* http://www.theiacp.org/portals/0/pdfs/IACP_UAGuidelines.pdf.

[214] *Id.* at 2.

[215] *See supra* Part II.A.

[216] See *supra* Part II.B.

will let us tailor regulations. Our goal should be to control drone development and use without being overbroad, curtailing future innovation, and sacrificing benefits the technology offers today. There is flexibility to keep humans "in the loop" when we want them there, and "out of the loop" when we do not. A machine's decision-making authority and independence from humans is a function of its engineering, and thus it can be a function of our deliberate choices.

For instance, regulations could restrict only certain stages of the loop, or treat different stages differently. At the *observe* stage, for example, we could establish rules about the locations or types of activities the system is permitted to observe, or the duration of the observation. These rules might not necessarily substantially decrease the amount of observation or restrict the places in which observation takes place. The amount and type of information that a machine gathers at the observe stage in the loop affects the machine's capacity to *orient* itself, the number and type of actions weighed when the machine *decides*, and the eventual *act* chosen and carried out.

So, for instance, regulations could require the machine on a "kill" mission to remain at the observational stage of the loop for a longer period of time, or mandate that it collect a larger amount of data, or collect it using a wider variety of sensors, if an initial scan of the scene indicates that a proportionality analysis would be particularly complex (perhaps because children may be present — as might be suggested by an observed person's height relative to the ground or to others around him, or by his gait, the objects near him, the pitch of his voice, or the pattern of his movements). In some circumstances, a more robust data set, created by lengthier and more detailed observation, may enable the final decision to be more discriminating and more accurate.

A regulatory regime could also distinguish between those decision-making loops the machine is permitted to carry out without human supervision and those requiring some level of human authorization. Laws could stipulate that a machine is permitted to autonomously complete the OODA Loop where the act that results from the completed loop is simply some form of movement through empty space. In contrast, we could structure the human-machine authority differently with loops where the act at the loop's end might be fatal, like releasing a missile or bullet.

For example, using Sheridan's autonomy spectrum discussed earlier, one could bar any system from operating at a level of autonomy higher than Level 5 when shooting, regardless of whether the system would be technologically capable of operating at a level beyond Level 5 if not artificially constrained. That is, if the *act* that is at the end of the OODA Loop is "shoot," the system could offer a complete set of action alternatives, suggest one (here, to shoot), and execute that suggestion only if the human approves — even if the system would be *technologically* capable of shooting without human permission and informing the operator of the act only if queried about it, consistent with Level 8 on Sheridan's scale.[217]

Our approach should depend on the values we want to promote. A regime that is primarily concerned with *accuracy*, for instance, could impose rigorous decision-making criteria, perhaps by requiring a drone to spend a great deal of time at the *observe* and *orient* stages, or by allowing the machine to *decide* to take action only if it has reached a sufficiently high confidence level. An "accuracy regime" might also provide for human veto power, or even affirmative authorization, of significant machine decisions.

A regime that is primarily concerned with *accountability* might look still different. Such a regime might impose accountability by requiring affirmative human sign-off of each machine-executed kinetic action, or only of particular decisions. But it could also permit substantial decision-making autonomy by the machines, even over decisions to kill, so long as a human (probably the military commander,

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[217] *Id.*

but perhaps the machine manufacturer, too) is responsible for any machine errors.

In reality, a comprehensive framework will incorporate a number of values including accuracy, accountability, machine efficiency, and so forth. We can calibrate a machine's independence within and across loops to reflect our preferences for these different standards. This brief sketch elaborates only a few of the many ways in which better technological understanding allows us to craft more thoughtful regulation. On this view, the question of whether a human is or must remain "in the loop" can be parsed into more focused questions such as *which* loop and which stages of that loop matter, and how *wide* the machine's discretion to complete the loop independently should be.

No set of regulations can be foolproof. Handing over decision-making authority to a machine necessarily entails some measure of risk that the machine will act unpredictably. Moreover, as discussed earlier, the OODA Loop is itself a simplification of the decision-making process. As a result, it may not be possible to perfectly segment regulation by stage of the loop, or across different loops. Policymakers should be informed of these risks, and their tolerance for these risks should be incorporated into the policy calculus and regulatory design.

B. The Moral Limits of Drone Technology.

The technological possibilities of drones may be endless. And yet, while drones may soon be able to perform the full range actions of human actions (and more), we must remain aware of potential limits on a machine's ability to replicate human decision-making in all ways. While tomorrow's drones may be able to kill our enemies and hunt down wrongdoers better than humans can today, will they be able to engage in moral reasoning? Will they be able to weigh the costs and benefits, the right and wrong, of spying on someone, or taking a life? Do we want them to?

The answers to these questions are not yet clear. Scholars and technical experts in the emerging field of robot ethics are actively exploring how future systems can integrate morals at the level of a machine's programming.[218] Scientists and philosophers are debating in tandem the theoretical principles — whether consequentialist, utilitarian, deontological, or some admixture — in which that governing code should be grounded.[219] Through these conversations, the competing views of the content and meaning of autonomy that lurk in

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[218] *See*, *e.g.*, Ronald C. Arkin, *Governing Legal Behavior: Embedding Ethics in a Hybrid Deliberative/Reactive Robot Architecture*, TECH. REP. GIT-GVU-07-11 (2009) [hereafter Arkin, *Governing Legal Behavior*], *available at* http://www.cc.gatech.edu/ai/robot-lab/online-publications/formalizationv35.pdf; Russell W. Robbins & William A. Wallace, *Decision Support for Ethical Problem Solving: A Multi-Agent Approach*, 43 DECISION SUPPORT SYS. 1571 (2007), *available at* http://www.sciencedirect.com/science/article/pii/S0167923606000418; Bruce M. McLaren, *Computational Models of Ethical Reasoning: Challenges, Initial Steps, and Future Directions*, IEEE INTELLIGENT SYS. 2-10 (July/Aug. 2006), *available at* http://tinyurl.com/88jbkae; Thomas M. Powers, *Deontological Machine Ethics*, AAAI TECH. REP. FS-05-06 79-86 (2005), *available at* http://www.aaai.org/Papers/Symposia/Fall/2005/FS-05-06/FS05-06-012.pdf; Bruce M. McLaren, *Extensionally Defining Principles and Case in Ethics: An AI Model*, 150 ARTIFICIAL INTELLIGENCE J. 145 (2003), *available at* http://tinyurl.com/6w8wwhr. *See also* SAMIR CHOPRA & LAURENCE F. WHITE, A LEGAL THEORY FOR AUTONOMOUS ARTIFICIAL AGENTS (2011).

[219] *See*, *e.g.*, Carl Shulman et al., *Which Consequentialism? Machine Ethics and Moral Divergence*, at 2 (The Singularity Institute 2009), *available at* http://singinst.org/upload/machine-ethics-moral-divergence.pdf (commenting that "the picture that emerges" when one considers establishing a canonical theory for machine ethics "is one of deep confusion: we have no idea what utility function to endow an explicit moral agent with," and concluding, "current moral theories are inadequate for machine ethics").

discussions about the use of advanced technologies will come home to roost in machine systems architecture. This will force the explication, quantification, and systemization of law and values with a more exquisite precision than ever before.

The decision sequence of the United States Army Soldier's Guide offers a useful glimpse of a lingering problem with translating carbon ethics into silicon programming.[220] "The Ethical Reasoning Process" offered in the Army Soldier's Guide is designed to help soldiers respond thoughtfully to ethical dilemmas, or situations in which soldiers "cannot simultaneously honor two or more values and follow given rules while accomplishing the mission.[221] One such hypothetical scenario is the dilemma of "The Checkpoint":

> Two days after a suicide car-bombing killed four soldiers at a checkpoint, another unit is operating a similar checkpoint some distance away. The unit was recently involved in offensive operations but was beginning the transition to stability operations. Unit training has emphasized the importance of helping the citizens return to a "normal" lifestyle. Nonetheless, the events of the previous day demonstrate that the enemy is still active, and will use civilian vehicles loaded with explosives to kill themselves in an attempt to also kill U.S. soldiers. At this time, soldiers at the checkpoint notice a large civilian passenger vehicle approaching at a high rate of speed.[222]

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[220] *See* UNITED STATES ARMY FIELD MANUAL NO. 7-21.13, THE SOLDIER'S GUIDE (Feb. 2004), http://www.milsci.ucsb.edu/UCSB_Army_ROTC/Links_files/FM%20721.13,%20The%20Soldier's%20Guide.pdf.

[221] *Id.* at 1-29–1-30.

[222] *Id.* at 1-30.

The Guide sets out a four-step process for soldiers to think through this dilemma.[223] Step 1 directs the service member to define the problem.[224] Step 2 instructs the soldier to "[k]now the relevant rules and values at stake," including the law, administrative rules, rules of engagement, command policies, and Army values.[225] At Step 3, the individual must "[d]evelop possible courses of action (COA)" and "evaluate them" using criteria excerpted here:

> a. Rules — Does the course of action violate rules, laws, or regulations?
> b. Effects — After visualizing the effects of the course of action, do you foresee bad effects that outweigh good effects?
> c. Circumstances — Do the circumstances of the situation favor one of the values or rules in conflict?
> d. "Gut check" — Does the course of action "feel" like it is the right thing to do? Does it uphold Army values and develop your character or virtue?[226]

At Step 4, the final stage in the process, the Guide concludes, "Now you should have at least one COA that has passed Step 3. If there is more than one COA [that has passed Step 3], choose the course of action that is best aligned with the criteria in Step 3."[227]

Although it may be possible to code the processes at Steps 1, 2, 3(a)-(c), and 4 into automated systems, for now, the Guide's Step 3(d) remains, "clearly outside the scope of

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223 *Id.*
224 *Id.*
225 *Id.*
226 *Id.*
227 *Id.*

autonomous systems"[228] even according to those who believe ethics can be embedded in machines. Scientists have successfully created a mechanical gut,[229] but the check proposed by the Army Guide needs a stomach of a different kind. Some doubt strongly that any artificial process could make a machine humane, much less imbue it with the ineffable human qualities the Army Soldier's Guide's Step 3(d) is intended to muster.[230] "Even if a robot was fully equipped with all of the rules from the Laws of War, and had, by some mysterious means, a way of making the same discriminations as humans make," scholars of this view argue, "it could not be ethical in the same way as is an ethical human."[231] "In most real-world situations, these [decisions] are a matter of interpretation."[232]

"What a piece of work is a man! How noble in reason! how infinite in faculties!"[233] But it is debatable, and perhaps unlikely, that Man can play God and create machines with the reason and faculties to make complex moral decisions. The debate over ethical robotics reflects profound disagreement over the nature of morality and the extent to which an act sounding in moral judgment can be disaggregated into component parts[234] — much less coded, however

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[228] Arkin, *Governing Legal* Behavior, *supra* note 218, at 51.
[229] *Scientists Create Artificial Gut*, BBC, Nov. 10, 2006, *available at* http://news.bbc.co.uk/2/hi/health/6136546.stm.
[230] *See* PATRICK LIN, KEITH ABNEY & GEORGE A. BEKEY, ROBOT ETHICS: THE ETHICAL AND SOCIAL IMPLICATIONS OF ROBOTICS 121 (2012) ("To be humane is, by definition, to be characterized by kindness, mercy, and sympathy, and to be marked by an emphasis on humanistic values and concerns. These are all human attributes that are not appropriate in a discussion of software for controlling mechanical devices.").
[231] *Id.*
[232] *Id.*
[233] WILLIAM SHAKESPEARE, HAMLET act 2, sc. 2.
[234] For explorations, *see*, *e.g.*, PHILIPPA FOOT, NATURAL GOODNESS (2003); Elizabeth Anderson, *Practical Reason and*

painstakingly, into an algorithmic rational choice process. The gap between those who believe that the human moral decision-making process is replicable and those who believe it is indissoluble and irreplaceable will be hard to bridge. More to the point, the disagreement is not likely to be settled before the practical question of whether and how to treat increasingly autonomous technologies presses too urgently to avoid. Our discussion of machine systems and autonomy provides a language that can be used to structure a regulatory regime for tomorrow's technologies today. With it, we should act.

V. CONCLUSION

The present debate over whether humans are "in the loop" or "out of the loop" has an all-or-nothing feel. It does not adequately account for the complexity of the technology it considers. This complexity actually can be helpful to policy makers, so long as it is explored clearly and thoughtfully. We can keep the human "in the loop" when we want her there, leave her "out of the loop" when we determine that her attention is more usefully directed elsewhere. Many permutations are possible, for there are many degrees of autonomy and many ways in which machines may or may not exhibit it.

As technology advances, legal, cultural, and political considerations will increasingly act as the primary limits on the capabilities of machine systems. These concerns do impose real boundaries.[235] Many regulatory permutations are possible, for there are many degrees of autonomy. With this insight, we can begin developing smart laws that serve both our security and our values.

Incommensurable Goods, *in* INCOMMENSURABILITY, INCOMPARABILITY, AND PRACTICAL REASON 90-109 (1998) (Ruth Chang, ed.).

[235] Fielding, *supra* note 208 (describing how political opposition halted plans to develop nuclear-powered drones).