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

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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 former CIA Director Leon Panetta.[1] And drones have already been introduced over our domestic skies, patrolling the U.S.-Mexico border[2] and assisting with law enforcement efforts.[3] Congress has voted to accelerate this trend, directing the Federal Aviation Administration to rethink 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*, ATLANTIC MONTHLY, Dec. 2010, 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, 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, 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 the drone?*, THE NEW YORKER, May 14, 2012, at 46, *available at* http://www.newyorker.com/reporting/2012/05/14/120514fa_fact_paumgarten.

[4] Nick Wingfield & Somini Sengupta, *Drones Set Sights on U.S. Skies*, N.Y. TIMES, Feb. 17, 2012, 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 just 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, or act on their own. In engineering speak, they are merely "automated."

The drones of tomorrow are expected to leap from automation to "autonomy." Tomorrow's sophisticated machines will have the ability to execute missions without guidance from a human operator. 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] Today's automated drones raise difficult policy questions, but those questions will seem pedestrian compared to the issues created by tomorrow's autonomous systems.

Regulations for the drones of today should be crafted with an eye toward the technologies of tomorrow. Policymakers must better understand how the next generation of autonomous drones will differ from the merely automated machines of today. The distinction between automation and autonomy is vital. 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 in-

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[5] PETER W. SINGER, WIRED FOR WAR: THE ROBOTICS REVOLUTION AND CONFLICT IN THE TWENTY-FIRST CENTURY 110 (2009) [hereinafter SINGER, WIRED FOR WAR].

[6] James Trew, *Robo-Guard the South Korean correction service robot says "stay out of trouble" (video)*, ENGADGET, (Apr. 15, 2012, 9:35 AM), http://www.engadget.com/2012/04/15/robo-guard-south-korean-robotic-guard/.

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

[8] Nick Bilton, *Disruptions: At Amazon, the Robot World Comes a Little Closer*, BITS: N.Y. TIMES TECH. BLOG, (Mar. 25, 2012, 1:58 PM), http://bits.blogs.nytimes.com/2012/03/25/disruptions-at-amazon-the-robot-world-comes-a-little-closer/.

[9] *See* Bernd Debusmann, *More drones, more robots, more wars?*, REUTERS, Jan. 31, 2012, in.reuters.com/assets/print?aid=INDEE80U04120120131; *see also* SHANE HARRIS, OUT OF THE LOOP: THE HUMAN-FREE FUTURE OF UNMANNED AERIAL VEHICLES, 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. 1 (2011).

creasingly 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, autonomy, and "the loop" relies on language too imprecise to draw out and analyze the relevant differences between drones and predecessor technologies. 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 not only those deployed today but also their even more sophisticated progeny of tomorrow.

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 submission to laws which 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 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

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[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 moral autonomy of Immanuel Kant).

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

[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.'" (citing Compassion in Dying v. Washington, 79 F.3d 790, 813–14 (9th Cir. 1996))).

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 discussion is fraught with terms that are both loaded and vague. The stakeholders in debates about the appropriate uses of drones are varied,[18] the technology is developing rapidly,[19] and the resolution of the questions it raises 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. It is difficult to structure a thoughtful debate and design an effective regulatory regime without first understanding drone technology, including how it functions and how it differs from yesterday's weapons of war. But we must understand this technology because, as drone expert Peter Singer has observed, drones' "intelligence and autonomy is growing. . . . The law's not ready for all this."[21]

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. We introduce this vocabulary here to explain how tomorrow's drones will differ from today's, outline the policy issues posed by the drones of tomorrow, and suggest possible approaches to regulation.

Part I of this Article offers a detailed discussion of how drones make decisions and explains the distinction between automation and autonomy. Part II tracks the development of drones past, present, and future, and demonstrates through examples how drones are expected to evolve from automated to autonomous

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[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.

[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, http://articles.latimes.com/2012/jan/26/business/la-fi-auto-drone-20120126.

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

machines. Part III highlights the difficult policy questions posed by tomorrow's drones, and explains how policymakers can use this Article's models of autonomy and of drone decision-making to craft smart, targeted regulations that protect both our security and our privacy. The Article then concludes.

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.

I. 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 an especially 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

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

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[22] For detailed discussions of John Boyd's development of the OODA Loop, see generally Robert Coram, Boyd: The Fighter Pilot Who Changed the Art of War (2002); Grant T. Hammond, The Mind of War: John Boyd and American Security (2001); Frans P.B. Osinga, Science, Strategy and War: The Strategic Theory of John Boyd (2006).

[23] *See* U.S. Air Force, UNMANNED AIRCRAFT SYSTEMS FLIGHT PLAN, 2009–2047 16 (2009), http://www.fas.org/irp/program/collect/uas_2009.pdf [hereinafter 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 no 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.

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] It has gained purchase in other fields too, including in business, sports and engineering—basically "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, sug-

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[25] Berndt Brehmer, Dep't of War Studies, Swedish Nat'l Def. College, Remarks at the 10th Int'l Command and Control Research and Technology Symposium: The Dynamic OODA Loop: Amalgamating Boyd's OODA Loop & the Cybernetic Approach to Command and Control, at 2 (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] *See* McIntosh, *supra* note 25, at 27; Brehmer, *supra* note 25, at 2.

[29] *See* Brehmer, *supra* note 25, at 2.

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

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

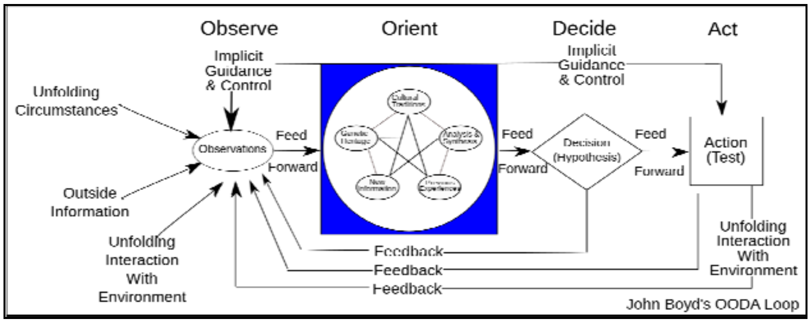
[34] *See, e.g.*, Eric Sholes, Aviation and Missile Research, Dev. And Eng'g Ctr., Remarks at the IEEE Aerospace Conference Digest: Evolution of a UAV Autonomy Classification Taxonomy, at 1, *available at* http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4161585.

gests a four-stage information-processing model that tracks OODA: (1) Information Acquisition; (2) Information Analysis; (3) Decision Selection; and (4) Action Implementation.[35]

The OODA Loop is not flawless. 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 because it includes constant feedback and integration among the different stages.[37] Still, the OODA Loop offers a useful lens for understanding system design.[38] It also allows a relatively 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

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[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 et al., *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.

[39] *Id.* at 593.

[40] *OODA loop*, WIKIPEDIA, http://en.wikipedia.org/wiki/File:OODA.Boyd.svg#file (last visited Mar. 19, 2013); *see also* McIntosh, *supra* note 25, at 27.

[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.").

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 estimates 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 which he can act. He may determine, for instance, that the boulder is too heavy to push aside and too tall to scale, but he may 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 perhaps not without the risk of 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, may be far more difficult for Hal. Hal must be built to understand 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 to determine accurately possible paths around the boulder. Depending on the characteris-

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[42] *See id.*

tics 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 the saying goes, "garbage in, garbage out"—or, to use the language of the OODA Loop, faulty information at the *observe* stage affects the rest of the process. Deficiencies at the first stage in the OODA Loop will curtail the options available to Hal later in 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. Although 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 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 so 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 ninety degrees, advance five feet, and then turn right. It is also possible to structure decisions in sequence. If Hal decides after executing the preprogrammed maneuver that there are no more roadblocks, its instruction might be to move forward. And if the block remains, Hal's programming might direct that Hal 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 cannot 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 boulder. And Hal's ability to go around the boulder will be limited if it is not equipped to successfully traverse the terrain on either side of the boulder.

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 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"

Unlike humans, all machines are not created equal. Compare the 1983 Apple Lisa to the contemporary MacBook, or a Cold War era U-2 spy plane to the surveillance and combat drones of today and tomorrow.[43] In each case, the latter differs meaningfully from the former, but 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 that the best way to evaluate whether and how these machines

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[43] *See infra* Part II.

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 although 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 entities are capable of being "independent in the establishment and pursuit of their own goals."[47] An automated process "simply replace[s] routine manual processes with software/hardware ones that follow a step-by-step sequence that may still include human participation."[48] An autonomous process 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

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[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 10 (2009), 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 389 (1999), *available at* http://dx.doi.org/10.1016/S0952-1976(99)00010-X.

[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.*

agency, which is captured by *volition*, or "choice in action or thought," and *intent*, or deliberate "pursuit of goals."[53] Truly autonomous machines may also actually be able to learn, meaning they can draw conclusions based on past experience and incorporate these lessons into future actions.[54]

This baseline distinction between automation and autonomy offers a useful starting point, but more is needed.[55] Autonomy is a complex concept with many components that cannot be captured simply by parsing decision-making independence. Capsule definitions are too coarse because there is no bright-line distinction between automated and autonomous technologies. The better approach 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 to function; (2) the machine's ability to function successfully despite *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.

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[53] *Id.* The technical definitions provided 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." *Automation definition*, MERRIAM-WEBSTER ONLINE DICTIONARY, http://www.merriam-webster.com/dictionary/automation (last visited Mar. 19, 2013). "Autonomy" is defined as "[t]he quality or state of being self-governing; especially: the right of self-government." *Id.*

[54] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 75–77.

[55] *See* TROY B. JONES & MITCH G. LEAMMUKDA, REQUIREMENTS-DRIVEN AUTONOMOUS SYSTEM TEST DESIGN: BUILDING TRUSTING RELATIONSHIPS 1 (2011), 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.

1. The First Attribute of Autonomy: Frequency of Operator Interaction

The first attribute of machine autonomy is the frequency with which an operator must interact with the machine in order for the machine to successfully perform its mission—in shorthand, a machine's "independence." Autonomous machines require less frequent operator interaction than automated machines. In an extreme case, the operator could just 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 automated the system becomes, until finally, it is simply remote-controlled.[59]

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

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[58] *Id.* at 5.

[59] *Id.*

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, Hal 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, these abilities 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 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 objects it has already encountered have

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[60] *Id.* at 2.

[61] *Id.*

moved since the 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 to complete its assigned mission without guidance from a human operator. In shorthand, this attribute measures a machine's "discretion."[62] The gravamen of assertiveness is the system's ability to alter independently the *means* it uses to achieve the human-designed *ends*. And 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 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

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[62] *Id.* at 9.

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. Assume that under normal circumstances, Hal will only evaluate actions with a 90% likelihood of success at the *decide* stage. If Hal is not assertive, it will stop in its tracks, retreat, or call for human help. But a more assertive machine, after 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 the 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 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.

These three key components of autonomy may be combined in many ways. As a result, "[l]ike intelligence and consciousness," autonomy is best conceived of as existing on a spectrum.[63] Some machine systems would clearly lie on the "automated" end, 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 that illustrated the OODA Loop. In some versions, Hal was operated like a tool. In others, the robot more closely resembled a teammate.[64]

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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*, 6541 LECTURE NOTES IN COMPUTER SCI. 172 (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*, 5619 LEC-

Formulations of the autonomy spectrum have evolved along with the machines they describe. Thomas Sheridan, the engineer and scholar introduced above, developed a ten-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] A machine at Level 1 on Sheridan's spectrum is automated; at Level 10, it is fully autonomous. Notice below that Levels 2 through 5 focus on the allocation of decision-making authority between the human and machine. By contrast, Levels 6 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.

TURE NOTES IN COMPUTER SCI. 935 (2009), *available at* http://www.springerlink.com/content/l112348134205684h/.

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

[66] Coppin & Legras, *supra* note 35, at 592.

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

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 it might be dependent on humans at the decision and action stages.[68] When the Air Force Research Lab (AFRL) released its own eleven-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

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[68] Parasuraman et al., *supra* note 35, at 289; Sholes, *supra* note 34, at 1.

[69] Sholes, *supra* note 34, at 2–3.

[70] *Id.* at 2.

[71] *Id.*

[72] *Id.* at 3.

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

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

Level	Observe	Orient	Decide	Act
0	Flight control sensing and 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 diagnosis and resource management.	On-board trajectory planning; optimizes for current and 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 the AFRL model 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. But it might achieve only Level 5 at the *decide* stage, making it able to avoid collisions with objects in its environment but still need human assistance to realize more substantial objectives.[74]

Humans need never be completely absent from the Loop. 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 addition to the state of the art, play an important role

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[73] *Id.*

[74] *Id.* at 3–5.

[75] JONES & LEAMMUKDA, *supra* note 55, at 8.

in the design of our machine systems.[76] Economic tradeoffs and value choices may be expressed through a machine's coding.

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

Although America's war drones today exhibit characteristics both of automation and autonomy, they are primarily only automated systems. The Global Hawk reconnaissance drone has the ability to take off and land unassisted, for instance.[79] The human operator need only press a button and direct it to take off.[80] But 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

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[76] *See* Parasuraman et al., *supra* note 35, at 287; *infra* part III; *see also* BILL YENNE, BIRDS OF PREY: PREDATORS, REAPERS AND AMERICA'S NEWEST UAVS IN COMBAT 27 (2010). Of course, particularly when it comes to militarized weapons systems, there may be great pressure to make a system as technologically advanced as possible.

[77] Parasuraman et al., *supra* note 35, at 289.

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

[79] SINGER, WIRED FOR WAR, *supra* note 5, at 36.

[80] *Id.*

[81] *Id.*

[82] *See* AIR FORCE FLIGHT PLAN, *supra* note 23, at 26–27.

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 may 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 permit machines to become. To illustrate, we move now from abstract concepts and vocabulary to history and detail, as we consider the drones of yesterday, today, and tomorrow.

II. DRONE WARFARE: YESTERDAY, TODAY, AND TOMORROW

To understand today's warfare technology, we must compare it with the technologies that came before. And it is important to focus on the relevant points of comparison. Contrasting today's Predator drones with the clubs, arrows, and muskets of yesteryear is interesting but, for our purposes, it is not very useful. We highlight here weapons that have exhibited some level of automation.

Before proceeding, we offer two notes of caution. First, drone technology is rapidly advancing, and much of the state of the technology is classified and unavailable to the general public. Our discussion of current and future drone technologies is based on 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 outlined here.

Second, our discussion of drone technology focuses on combat and surveillance drones. 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, as well as 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

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[83] *Id.*

be used as weapons—and he promptly capitalizes on this discovery by taking control of a competing group's watering hole by clubbing its leader to death. However warfare actually began, it has been evolving ever since. The evolution of warfare has been periodically marked by paradigm shifts in warfare technology called "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 the year 1300.[85]

Machine autonomy is a relatively recent phenomenon, but automated systems have been used in warfare since at least 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] 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 German military also weaponized remote-controlled machines during World War II, deploying the land torpedo "Goliath," a remote-controlled car loaded with explosives that was driven into enemy tanks and bunkers.[90] Germany 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

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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.

[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.

ability to navigate the OODA Loop independently, and thus each falls squarely at Level 0—"remotely piloted vehicle"—on the Air Force's eleven-level autonomy spectrum.

Early automated drones were also used for surveillance and reconnaissance missions. For example, the Ryan Firebee II was a spy plane that was used during the Vietnam War and had a range of nearly 900 miles and a flight endurance of more than one hour.[92] The "Lightning Bug," another reconnaissance drone, was 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 controller at a remote control station could watch their progress on television as though he was aboard."[94] Although they represented a huge leap forward in military technology, they are still relatively primitive by today's standards. They likely belong at Level 0 on the Air Force's eleven-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 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 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 leap forward, a Pioneer drone became responsible for the first-ever surrender of human soldiers to an unmanned system when Iraqi soldiers

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[92] YENNE, *supra* note 76, at 14.

[93] *Id.* at 15.

[94] *Id.* at 15–16.

[95] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 53.

[96] *Id.* at 55.

[97] *Id.*

[98] *Id.* at 56–57; YENNE, *supra* note 76, at 27.

surrendered to the Pioneer by waving white bedsheets and undershirts at the mechanized soldier in the sky.[99]

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 what it calculated to be the right time to hit the desired target.[102] When Paul Tibbets dropped "Little Boy" from the *Enola Gay* onto the city of Hiroshima on August 6, 1945, Tibbets used a Norden bombsight to ensure that he dropped the uranium bomb at the appropriate moment.[103]

Precision targeting took a huge leap forward with the invention of laser-guided bombs and cruise missiles, perhaps the twentieth century's most significant development in unmanned war technology. 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] In early models, the human had to continuously keep the laser on the target until the bomb landed.[106] Later technology allowed the human to exit the scene while the bomb completed the mission on its own.[107]

Laser-guided bombs were 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

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[99] SINGER, WIRED FOR WAR, *supra* note 5, at 57; YENNE, *supra* note 76, at 27.

[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 INST., Jan. 28, 2009, www.brookings.edu/research/articles/2009/01/28-robots-singer [hereinafter Singer, *In the Loop?*].

[103] SINGER, WIRED FOR WAR, *supra* note 5, at 51.

[104] *Id.* at 57.

[105] *Id.*

[106] *Id.*

[107] *Id.*

on the autonomy spectrum. 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 eleven-level autonomy spectrum.[108] Moreover, laser-guided bombs had the critical weakness of functioning poorly in bad weather.[109] Dust, haze, or smoke could make the bomb's laser guidance capabilities virtually useless.[110]

Cruise missiles are more sophisticated weapons than laser-guided bombs because they fly themselves using preset coordinates or recognition software.[111] The first cruise missiles included the pioneering German Fiesler Fi.103, which was introduced during World War II.[112] Early cruise missiles lacked precision guidance, meaning their ability to hit a specified enemy target was quite limited.[113] Technological advances eventually culminated in the Tomahawk missile, which was used in the Middle East during the Gulf War.[114]

Yet when we analyze 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.[115] The Tomahawk could not be programmed to attack a particular target midflight; moreover, "[i]t could not react to change" in its environment.[116] Furthermore, although the ability to instruct a Tomahawk to embed itself at a particular site diminished the need for constant human guidance while in flight, the missile had to travel over terrain that had already been mapped out and preprogrammed into its computer memory.[117] Though the Tomahawk's reliance on its human operator was minimal once it was fired, its ability to manage environmental uncertainty was very limited.[118]

The history presented here is necessarily brief, but these vignettes offer a few important lessons that apply broadly to

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

early forays into mechanized warfare. The most important point is that although these technologies do exhibit some characteristics of automation, they have almost none of the characteristics of autonomy: 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; thus one of three attributes of autonomy was wholly missing. Moreover, if the communications link failed, the systems often became 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.[119]

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 essentially were either target drones created to be destroyed in practice, or missiles designed to destroy enemy facilities. 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, 2001, global War on Terror vastly expanded the use of military drones.[120] Several factors drove this trend. By 2011, technology had improved to the point where the widespread use of drones became both feasible and attractive. Although the early drone technology described above was hampered by technical challenges, including inadequate communications equipment and a

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[119] YENNE, *supra* note 76, at 16.

[120] SINGER, WIRED FOR WAR, *supra* note 5, at 61 (quoting an industry report stating that "[p]rior to 9/11, the size of the unmanned vehicle market had been growing, but at an almost glacial place").

limited ability to integrate an airplane's flight and targeting systems,[121] new technologies have permitted drones to become more effective.[122]

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 World War II in several important respects. They are not confined to a particular battle space, driving demand for twenty-four-hour, seven-day-a-week global surveillance that can be more effectively accomplished with a drone than with a human pilot.[123] Targeted drone killings have provided a way to confront terrorists that hide among civilian populations.[124] Diminished political tolerance for military casualties has also made drones more politically palatable, because they keep soldiers farther from the battlefield and preserve the lives of American servicemen.[125] The weaponry itself is also improved; some argue that the Predator drone's smaller Hellfire missiles probably cause less collateral damage and loss of civilian life than larger alternatives launched from distances further away.[126] Scholars have suggested that increased judicial scrutiny of detention practices may have also increased the appeal of targeted drone killings.[127] Over time, the military has

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[121] YENNE, *supra* note 76, at 23.

[122] SINGER, WIRED FOR WAR, *supra* note 5, at 58.

[123] *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 enabling fewer humans to conduct surveillance over a larger terrain).

[124] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 36; Jonathan Ulrich, Note, *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).

[125] U.N. General Assembly, Study on Targeted Killings: Rep. of the Special Rapporteur on Extrajudicial, Summary, or Arbitrary Executions, ¶27, 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.").

[126] Jane Mayer, *The Predator War: What are the risks of the C.I.A.'s covert drone program?*, THE NEW YORKER, Oct. 26, 2009, *available at* http://www.newyorker.com/reporting/2009/10/26/091026fa_fact_mayer ("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.").

[127] 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, ex-

lowered its cultural opposition to drones, particularly its resistance to the notion that a plane should be piloted by a computer rather than a human pilot.[128] And, of course, there are cost concerns: Drones are often significantly cheaper to operate than manned vehicles.[129]

Many of these same trends may spur increased use of drones inside the United States, too. As the country winds down its military actions abroad, it will bring home many of the 1800 drone aircraft that the U.S. military owns.[130] Congress has instructed the Federal Aviation Administration (FAA) to develop regulations for the domestic use of drones, first for law enforcement purposes, and, by 2015, for commercial purposes too.[131] For states facing budget crises, drones promise to be low-cost and highly efficient means of law enforcement. Drones have been deployed along the Mexican-American border to monitor for illegal entrants into the United States.[132] And they have already been used for more routine law enforcement duties such as assisting with arrests.[133]

Importantly, these drones are not an undifferentiated mass. The machines are equipped with different capabilities. 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. We consider a few examples below.

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 current centerpiece of America's aerial drone program is the Predator, a 27-foot, 1130-pound airplane

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tradition, and release. The more complicated detention has become, the more attractive the option of targeted killing seems to be.").

[128] YENNE, *supra* note 76, at 27.

[129] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 114.

[130] Sarah Childress, *The Military's Plan for Drones at Home*, PBS FRONTLINE, (June 19, 2012, 2:14 PM), http://www.pbs.org/wgbh/pages/frontline/foreign-affairs-defense/the-militarys-plans-for-drones-at-home/.

[131] Wingfield & Sengupta, *supra* note 4. As Nick Paumgarten points out, "Air 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.

[132] Booth, *supra* note 2.

[133] Paumgarten, *supra* note 3, at 46, 58.

that can spend 24 hours in the air at a time.[134] The Predator boasts incredibly sophisticated surveillance capabilities. It has the ability to loiter over a target for long periods,[135] read a license plate from two miles away,[136] and monitor terrain below during day or night, through fog, cloud cover, or at night.[137]

The Predator was originally designed to conduct surveillance and was first deployed on reconnaissance missions over the Balkans in 1995 and 1996.[138] After September 11, the drone was outfitted with a payload of laser-guided Hellfire missiles, turning the Predator into a deadly war machine.[139] The Predator's surveillance capabilities are still critical, however, and this drone has been used to provide continuous, useful real-time surveillance to soldiers on the ground.[140] Although there is no human in the cockpit, each Predator mission still requires significant 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 the drone.[141]

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 3750-pound payload, a nearly ten-fold increase over the Predator's 450-pound payload weight limit.[142] Instead of the Hellfire, the Reaper often carries the Maverick missile, a larger bomb capable of more "heavy duty" tasks like busting tanks.[143] 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.[144] If two 1000-pound external fuel tanks are added to

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[134] Robert Valdes, *How the Predator UAV Works*, HOW STUFF WORKS, science.howstuffworks.com/predator.htm (last visited Mar. 19, 2013).

[135] YENNE, *supra* note 76, at 48.

[136] *Id.*; Andrew Callam, *Drone Wars: Armed Unmanned Aerial Vehicles*, 17 INT'L AFF. REV. (Winter 2010), *available at* http://www.iar-gwu.org/node/144.

[137] YENNE, *supra* note 76, at 32–33.

[138] *Id.* at 39.

[139] *Id.* at 43–45.

[140] *Id.* at 69.

[141] Valdes, *supra* note 134.

[142] AIR FORCE FLIGHT PLAN, *supra* note 23, at 26–27; *MQ-1B Predator*, U.S. AIR FORCE, Jan. 5, 2012, http://www.af.mil/information/factsheets/factsheet.asp?id=122 (last visited Mar. 19, 2013); *MQ-9 Reaper*, U.S. AIR FORCE, Jan. 5, 2012, http://www.af.mil/information/factsheets/factsheet.asp?id=6405 (last visited Mar. 19, 2013).

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

[144] AIR FORCE FLIGHT PLAN, *supra* note 23, at 26–27.

the Reaper, its endurance jumps to 42 hours.[145] 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.[146]

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 put it, "[a]s an aircraft, the Predator UAV is little more than a super-fancy remote-controlled plane."[147] Both the Predator and Reaper can be flown on one of three modes, ranging from remote-control flying, semi-autonomous monitored flight, and pre-programmed flight.[148] Each of these modes, however, requires frequent human interaction. The drones are unable to suggest sophisticated actions to human operators or make sophisticated decisions independently.

The military also deploys surveillance drones that, unlike Predators and Reapers, 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 in the air.[149] The Global Hawk has the ability to watch the ground below day and night, and through most types of weather.[150] 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."[151] The 30,000 pound drone requires "a small army of people to operate and service each plane,"[152] but the Global Hawk has begun

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

[146] U.S. AIR FORCE, *MQ-1B Predator*, *supra* note 142; U.S. AIR FORCE, *MQ-9 Reaper*, *supra* note 142.

[147] Valdes, *supra* note 134. 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).

[148] AIR FORCE FLIGHT PLAN, *supra* note 23, at 26–27.

[149] *Id.* at 27.

[150] Gayle Putrich, *Next generation of Global Hawks ready to roll*, FLIGHT INT'L, Aug. 16, 2010, http://www.flightglobal.com/news/articles/next-generation-of-global-hawks-ready-to-roll-346116.

[151] SINGER, WIRED FOR WAR, *supra* note 5, at 36.

[152] Paumgarten, *supra* note 3, at 53.

to climb up the autonomy spectrum. It might be placed at Level 1 or Level 2 on the Air Force's scale.

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 the Global Positioning System (GPS) to follow a predetermined flight path.[153] 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 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,[154] but it can also input its flight path into a computer and have the Raven do the rest.[155] The Raven can fly for 90 minutes, may 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 has the capability to adjust to the wind by itself. [156]

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.[157] (Indeed, many drones are operated with "joysticks that resemble video-game controls."[158] Some successful drone pilots got their start in their parents' basement playing Xbox and Playstation.[159]) Although these drones operate at the lower ends of the Air Force's autonomy spectrum, they do exhibit some of the 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 Af-

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[153] AIR FORCE FLIGHT PLAN, *supra* note 23, at 26.

[154] SINGER, WIRED FOR WAR, *supra* note 5, at 37.

[155] Paumgarten, *supra* note 3, at 54.

[156] *Id.*

[157] AIR FORCE FLIGHT PLAN, *supra* note 23, at 25.

[158] Mayer, *supra* note 126.

[159] Griffin McElroy, *Soldier became ace drone pilot by training on video games*, JOYSTIQ, (Feb. 7, 2009, 6:00 PM), http://www.joystiq.com/2009/02/07/soldier-became-ace-drone-pilot-by-training-on-video-games/; *see also* SINGER, WIRED FOR WAR, *supra* note 5, at 361.

ghanistan to detect improvised explosive devices (IEDs), is the size of a lawnmower and, at 42 pounds, weighs about as much as a three-year-old child.[160] A 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.[161] It can perform many functions. As if outfitted by James Bond's Q, PackBot carries with it a mine detector, a chemical and biological weapons sensor, and auxiliary power packs.

But although James Bond's human handlers never could quite control him, a PackBot heavily relies on its human operators to operate and to switch between and deploy the different tools.[162] A PackBot is equipped with a camera to peer at possible IEDs, but it simply transmits that information back to its controlling soldier and does not actually interpret the visual information itself.[163] 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. It ranks at the low end of the Air Force's autonomy spectrum, probably no higher than Level 1.

The SWORDS has a fearsome name, but its moniker may yet be an 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.[164] On the autonomy spectrum, however, SWORDS is in many ways even more primitive than the 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.[165] SWORDS is an archetypical automated but non-autonomous robot: It replaces human functions (lock, load, and fire) but does not supplant

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[160] *See* SINGER, WIRED FOR WAR, *supra* note 5, at 22.

[161] *Id.*

[162] *Id.*

[163] *Id.*

[164] *Id.* at 30.

[165] *Id.*

human decisionmaking.[166] SWORDS, therefore, probably belongs at Level 0 or 1 on the Air Force's autonomy spectrum.

3. *An Automated, Non-Autonomous Fleet*

Technical problems still hamper drones. Communications links between drones and their remote pilots are unreliable and "regularly cut out, forcing the robotic aircraft into automatic holding patterns."[167] 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 that these drones are able to execute missions "without ever exposing the pilot to a hostile environment."[168] Thus, these drones are useful because they replace human actions but not human decisionmaking—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), an air-defense technology that "automatically tracks and shoots down any missiles that have gotten past all other defenses and are too quick for humans to react to."[169] 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 aircraft and killing American soldiers.[170]

The Aegis sea defense system offers another example of the benefits, and potentially dire costs, of machines programmed to kill. The Aegis has four modes, ranging from "semiautomatic," in which a human controls the system and decides when and

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[166] *Id.*

[167] Noah Schachtman, *Report: U.S. Drone Goes Down Over Pakistan. Again.*, WIRED DANGER ROOM BLOG, (Jan. 25, 2010, 11:02 AM), http://www.wired.com/dangerroom/2010/01/us-drone-goes-down-over-pakistan-again/.

[168] Valdes, *supra* note 134.

[169] SINGER, WIRED FOR WAR, *supra* note 5, at 38.

[170] *Id.*

what to shoot, to "casualty," where the system is authorized to shoot without prior human authorization in order to keep a ship safe.[171] One risk associated with this system is that even in the less-autonomous modes, in which a human retains a veto over the system's decisions, the human operator may trust the machine more than his or her 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.[172] Even though the Aegis system's human operators had a veto over the decision to shoot, the operators allowed the machine to shoot.[173] The story illustrates the limitations of engineering in a different and painful way.

Today, America's drone fleet makes its military more potent than it has ever been before. The drones permit more continuous surveillance of enemies and more accurate 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, nonautonomous systems. Most of today's drones are at Levels 0, 1, or 2 on the autonomy spectrum.

C. *Tomorrow's Drones*

Although engineers and policymakers may disagree about whether today's drones truly are different from machines past, the systems of tomorrow will unite the two camps. The race is on to develop autonomous systems that can complete the OODA Loop better and faster than our rivals.[174] 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

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[171] *Id.* at 124.

[172] *Id.* at 124–25.

[173] SINGER, WIRED FOR WAR, *supra* note 5, at 125; HARRIS, *supra* note 9, at 10.

[174] *See* AIR FORCE FLIGHT PLAN, *supra* note 23, at 16.

today's technology, the conversations about tomorrow's will be still more fraught.

Tomorrow's drones will exhibit greater autonomy along all four stages of the OODA Loop. They will require less human interaction, navigate greater levels of environmental uncertainty, and enjoy higher levels of mission assertiveness. The military predicts that these increasingly autonomous machines will eventually be fully integrated into the fighting forces.[175] By 2025, the American armed forces are expected to be "largely robotic."[176] "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.[177] "We are seeing the very first stages of this technology."[178]

The next generation of drones will be able to take off and land without any human interaction.[179] The Phantom Eye, now a prototype, has 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.[180] In the future, drones may be able to perform one of the most difficult flight tasks—landing on an aircraft carrier—without any human control.[181] 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.[182] Drones will also be able to conduct surveillance without the need for a human operator to actively steer a camera to areas of interest. The next generation of Reaper drone, for instance, is expected to have the capability not only to "recognize and categorize humans and human-made objects" that it encounters, but also to "make sense of the changes . . . it is

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[175] *Id.* at 48.

[176] Project Alpha et al., *Unmanned Effects (UFX): Taking the Human Out of the Loop*, U.S. JOINT FORCES COMMAND (Sept. 2003), http://www.hsdl.org/?view&did=705224.

[177] SINGER, WIRED FOR WAR, *supra* note 5, at 110.

[178] *Id.*

[179] *See* AIR FORCE FLIGHT PLAN, *supra* note 23, at 39.

[180] *Boeing Phantom Eye Completes 1st Autonomous Flight*, BOEING COM., http://boeing.mediaroom.com/index.php?s=43&item=2276 (last visited Mar. 19, 2013).

[181] Hennigan, *supra* note 20.

[182] SINGER, WIRED FOR WAR, *supra* note 5, at 117.

watching, such as being able to interpret and retrace footprints or even lawn mower tracks."[183]

Drone technology may advance to the point where machines are able "to make combat decisions and act within legal and policy constraints without necessarily requiring human input."[184] Machine systems could 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.[185] These drones will increasingly take to the sea and ground, both of which are 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.[186] 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 surveillance missions, protectively patrolling harbors, and inspecting any suspicious ships it encounters.[187]

Novel technological trends include the push to develop micro-drones and nano-drones, some bio-mechanical and as tiny as the width of a human hair.[188] 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."[189] According to one observer, nano-drones add to the push beyond mere automation because their tiny designs "actually mandate that the systems will have to have high autonomy, carrying out their missions without human controllers."[190] Significant autonomy is necessary because the drones are too numerous for each to have an individual human controller; moreover, flying the micro machines

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[183] *Id.* at 116.

[184] AIR FORCE FLIGHT PLAN, *supra* note 23, at 41.

[185] *Id.*

[186] SINGER, WIRED FOR WAR, *supra* note 5, at 111.

[187] *Id.* at 115.

[188] *Id.* at 118.

[189] AIR FORCE FLIGHT PLAN, *supra* note 23, at 36.

[190] SINGER, WIRED FOR WAR, *supra* note 5, at 118–19.

may actually make most human operators nauseous.[191] 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 human operators possibly could.[192] Of course, nano-drones not fully controlled by humans may not go exactly where the operator wants them to go, or do exactly what she wants them to do.[193] 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.[194]

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."[195] Increasingly, the Air Force predicts, "humans will no longer be 'in the loop' but rather 'on the loop'—monitoring the execution of certain decisions."[196]

Human reliance on drones will continue to grow, along with an 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 without contact and direction from an operator are especially valuable.[197] Some systems deployed in combat or defensive positions must be able to react in circumstances that do not permit time for a human to give command.[198] And as the technology improves, drones may simply become better at executing a greater number of combat and surveillance tasks than humans.[199] As one commentator noted

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[191] *Id.* at 119.

[192] *See id.*

[193] *Id.* at 235.

[194] *See* AIR FORCE FLIGHT PLAN, *supra* note 23, at 34.

[195] *Id.* at 16.

[196] *Id.* at 41.

[197] Singer, *In the Loop?*, *supra* note 102.

[198] *Id.*

[199] SINGER, WIRED FOR WAR, *supra* note 5, at 63 (quoting Gordon Johnson of the Pentagon's Joint Forces Command).

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."[200]

III. LAW AND ETHICS FOR AUTONOMOUS SYSTEMS

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.[201] 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),[202] must increasingly be addressed at the design stage. Although a detailed discussion of these laws of war and their application to machine warfare is beyond the scope of this Article,[203] these questions must eventually be resolved. As the machines evolve, so too will the meaning of having a human "in the loop."

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

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[200] *Id.*

[201] Although 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 Article, these issues are grave, urgent, and clearly implicated by the shift towards greater autonomy.

[202] *See, e.g.*, 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); 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); Richard Murphy & Afsheen John Radsan, *Due Process and Targeted Killing of Terrorists*, 31 CARDOZO L. REV. 405 (2009); Ryan J. Vogel, *Drone Warfare and the Law of Armed Conflict*, 39 DENV. J. INT'L L. & POL'Y 101, 138 (2010); Kenneth Anderson, *Targeted Killing in U.S. Counterterrorism Strategy and Law* 34, 408 (May 11, 2009) (working paper), *available at* www.brookings.edu/research/papers/2009/05/11-counterterrorism-anderson.

[203] For thoughtful commentary, see Kenneth Anderson, *Efficiency in Bello and ad Bellum: Targeted Killing Through Drone Warfare*, (Sept. 23, 2011) (working paper), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1812124; *see also* Jenks, *supra* note 202, at 671.

should be discussed today, while the technology is still in a relatively nascent stage and the opportunity remains to control its development.[204] The embryonic state of the art offers policymakers a unique opportunity to think creatively and proactively about these systems' future development.[205] 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 around-the-clock aerial drones will erode our privacy and transform America into an Orwellian dystopia.[206] 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 swelling kill lists.[207]

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 introduced a bill that would prohibit the domestic use of drones by the government unless it first obtains a warrant or demonstrates that exigent circumstances exist.[208] The International Association of Chiefs of Police has provided a series of guidelines for the domestic use of drones.[209] Its recommendations include retaining

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[204] *See supra* Parts I–II.

[205] *Cf.* Ronald C. Arkin et al., Moral Decision-making in Autonomous Systems: Enforcement, Moral Emotions, Dignity, Trust, and Deception (2012), http://smartech.gatech.edu/jspui/bitstream/1853/40769/1/IEEE-ethicsv17.pdf.

[206] *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 generally* JAY STANLEY & CATHERINE CRUMP, PROTECTING PRIVACY FROM AERIAL SURVEILLANCE: RECOMMENDATIONS FOR GOVERNMENT USE OF DRONE AIRCRAFT (2011), http://www.aclu.org/files/assets/protectingprivacyfromaerialsurveillance.pdf.

[207] *See* Peter W. Singer, *Do Drones Undermine Democracy?*, N.Y. TIMES, Jan. 21, 2012, 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.").

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

[209] INT'L ASS'N OF CHIEFS OF POLICE, RECOMMENDED GUIDELINES FOR THE USE OF UNMANNED AIRCRAFT (2012), http://www.theiacp.org/portals/0/pdfs/IACP_UAGuidelines.pdf.

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.[210] But these proposals are neither fine-grained nor far-sighted enough.

If we do want to regulate drone technologies, a more nuanced view of machines will permit regulations to be tailored accordingly. Our goal should be to control drone development and use without being overbroad, curtailing future innovation, or 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 authority and independence from humans is a function of its engineering. The extent of drone authority and independence can be a function of our deliberate choices.

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. Debating 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 is unhelpful because it is too simplistic. As this Article 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.[211] 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.[212]

For example, 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. Importantly, these rules might not necessarily decrease the amount of observation or restrict the places in which observation takes place. The amount and type

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[210] *Id.* at 2.

[211] *See supra* Part I.A.

[212] *See supra* Part I.B.

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* 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 complete the OODA Loop autonomously 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, such as releasing a missile or bullet.

For example, using Sheridan's autonomy spectrum, regulations could bar any system from operating at a level of autonomy higher than Level 5 when shooting, regardless of whether the system had the technological capability to do so. That is, if the *act* that is at the end of the OODA Loop is to "shoot," the system could shoot 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.[213]

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

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[213] *Id.*

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 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 the machine to exercise substantial decision-making authority even over decisions to kill, so long as a human (probably the military commander, 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 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 segment regulation perfectly 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

Drones may soon be able to perform the full range of human actions (and more), but a machine may not be able to replicate human decisionmaking in every way. Although tomorrow's drones may be able to kill enemies and hunt down wrongdoers better than humans can today, will they be able to engage in moral reasoning? Will machines 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 exploring how future systems can integrate moral judgments at the level of a machine's programming.[214] And scientists and philosophers are debating the theoretical principles—whether consequentialist, utilitarian, deontological, or some combination—in which that governing code should be grounded.[215]

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.[216] "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."[217] 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 of-

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[214] *See, e.g.*, RONALD C. ARKIN, GOVERNING LETHAL BEHAVIOR: EMBEDDING ETHICS IN A HYBRID DELIBERATIVE/REACTIVE ROBOT ARCHITECTURE (2009), http://www.cc.gatech.edu/ai/robot-lab/online-publications/formalizationv35.pdf [hereinafter ARKIN, GOVERNING LETHAL BEHAVIOR]; THOMAS M. POWERS, DEONTOLOGICAL MACHINE ETHICS (2005), http://www.aaai.org/Papers/Symposia/Fall/2005/FS-05-06/FS05-06-012.pdf; Bruce M. McLaren, *Computational Models of Ethical Reasoning: Challenges, Initial Steps, and Future Directions*, IEEE INTELLIGENT SYS., July-Aug. 2006, at 2–10, *available at* http://tinyurl.com/88jbkae; 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; 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; *see also* SAMIR CHOPRA & LAURENCE F. WHITE, A LEGAL THEORY FOR AUTONOMOUS ARTIFICIAL AGENTS (2011).

[215] *See, e.g.*, CARL SHULMAN ET AL., WHICH CONSEQUENTIALISM? MACHINE ETHICS AND MORAL DIVERGENCE 2 (2009), 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, "[c]urrent [m]oral [t]heories [a]re [i]nadequate for [m]achine [e]thics").

[216] *See* UNITED STATES ARMY FIELD MANUAL NO. 7-21.13, THE SOLDIER'S GUIDE (2004), http://armypubs.army.mil/doctrine/DR_pubs/DR_a/pdf/fm7_21x13.pdf.

[217] *Id.* at 1-29 to 1-30.

> fensive 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 US soldiers.
>
> At this time, soldiers at the checkpoint notice a large civilian passenger vehicle approaching at a high rate of speed.[218]

The Guide sets out a four-step process for soldiers to think through this dilemma.[219] Step 1 directs the service member to define the problem.[220] 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.[221] 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?[222]

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."[223]

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[218] *Id.* at 1-29.
[219] *Id.* at 1-30.
[220] *Id.*
[221] *Id.*
[222] *Id.*
[223] *Id.*

Although it may be possible to code the processes at Steps 1, 2, 3(a)–(c), and 4 into automated systems, for now, the 'gut check' of Step 3(d) remains "clearly outside the scope of autonomous systems" even according to those who believe ethics can be embedded in machines.[224] Scientists have successfully created a mechanical gut,[225] but the check proposed by the Army Guide needs a stomach of a different kind. Some doubt that any artificial process could make a machine humane, much less imbue it with the ineffable human qualities the 'gut check' step is designed to muster.[226] "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."[227] "In most real-world situations, these [decisions] are a matter of interpretation."[228]

It may not be possible for us to create machines able to reason through complex moral decisions, notwithstanding our own infinite faculties. Debates about ethics and robotics reflect profound disagreement over the nature of morality and the extent to which an act sounding in moral judgment can be disaggregated into component parts[229]—much less coded, however 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 that it is irreplaceable will be hard to bridge. In any event, 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 be avoided. Our discussion of machine systems and autonomy provides a language

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[224] ARKIN, GOVERNING LETHAL BEHAVIOR, *supra* note 214, at 51.

[225] *Scientists Create Artificial Gut*, BBC, Nov. 10, 2006, http://news.bbc.co.uk/2/hi/health/6136546.stm.

[226] *See* Noel Sharkey, *Killing Made Easy: From Joysticks to Politics*, *in* ROBOT ETHICS: THE ETHICAL AND SOCIAL IMPLICATIONS OF ROBOTICS 111, 121 (Patrick Lin et al. eds., 2012) ("To be humane is, by definition, to be characterized by kindness, mercy, and sympathy, or 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.").

[227] *Id.*

[228] *Id.*

[229] For explorations, see, e.g., PHILIPPA FOOT, NATURAL GOODNESS (2003); Elizabeth Anderson, *Practical Reason and Incommensurable Goods*, *in* INCOMMENSURABILITY, INCOMPARABILITY, AND PRACTICAL REASON 90–109 (Ruth Chang, ed., 1997).

that can be used today to structure a regulatory regime for the technologies of tomorrow. With it, we should act.

CONCLUSION

The 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 drone technology. The technology's complexity actually can be helpful to policymakers, so long as it is explored clearly and thoughtfully. We can keep the human "in the loop" when we want her there, and leave her "out of the loop" when we determine that her attention is more usefully directed elsewhere. Many combinations 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 choices can impose real boundaries.[230] Much is possible, for there are many degrees of autonomy. With this insight, we can begin developing smart laws that better serve both security and our values.

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[230] Nick Fielding, *U.S. Draws Up Plans for Nuclear Drones*, THE GUARDIAN, Apr. 2, 2012, http://www.guardian.co.uk/world/2012/apr/02/us-plans-nuclear-drones (describing how political opposition halted plans to develop nuclear-powered drones).