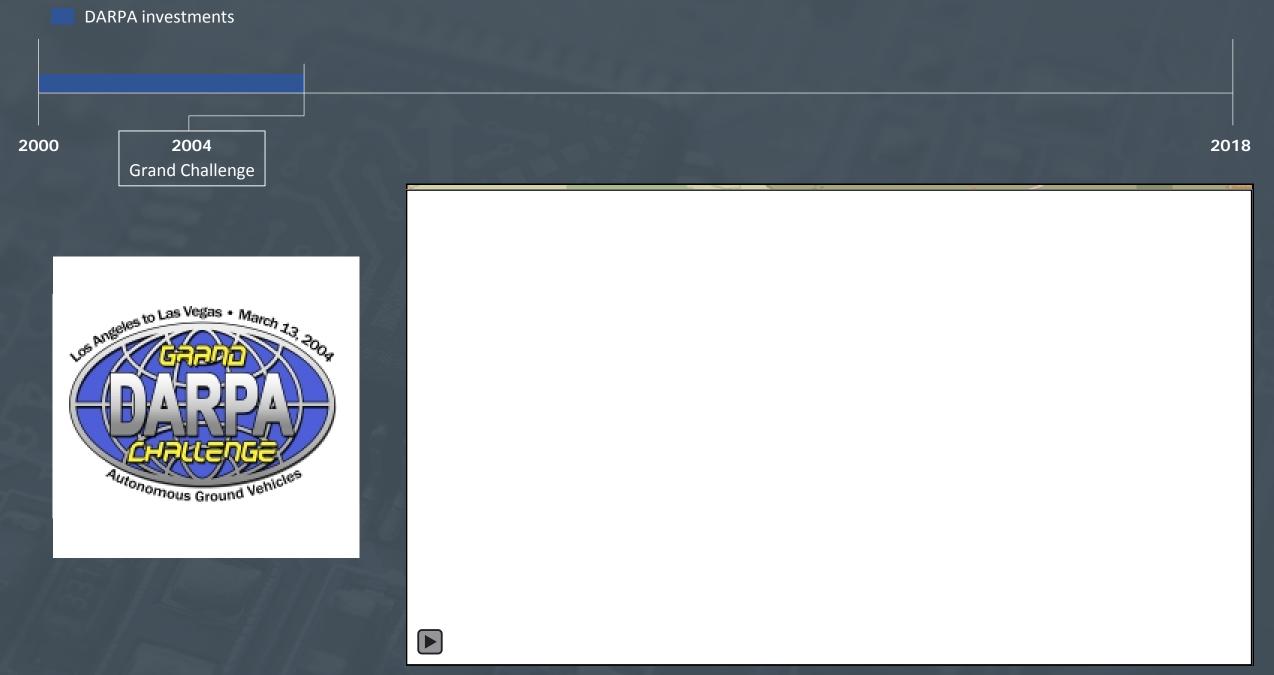
## Creating Inflections

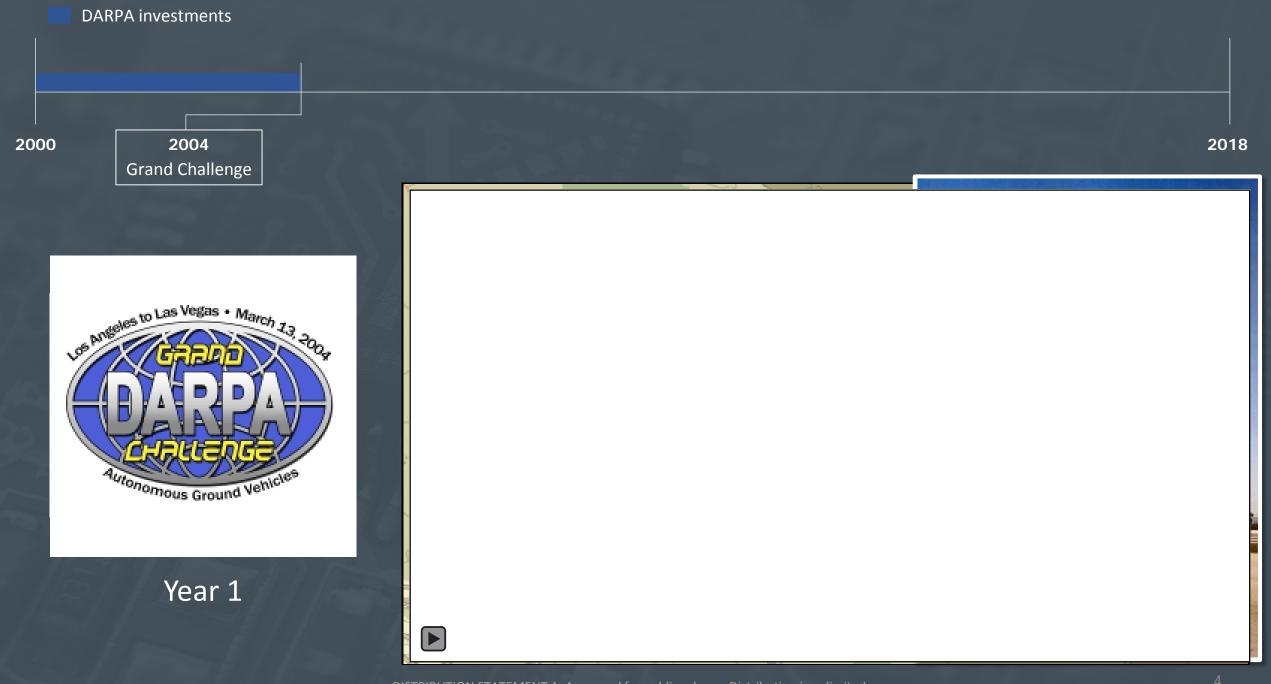
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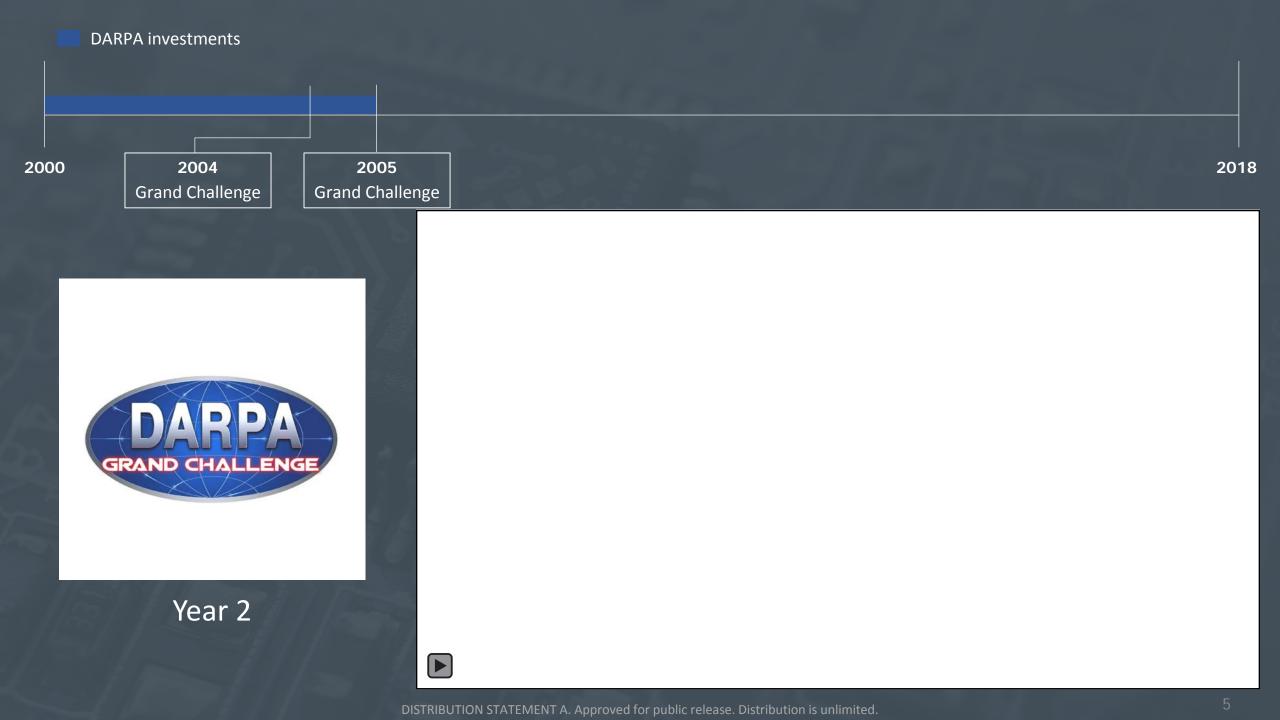


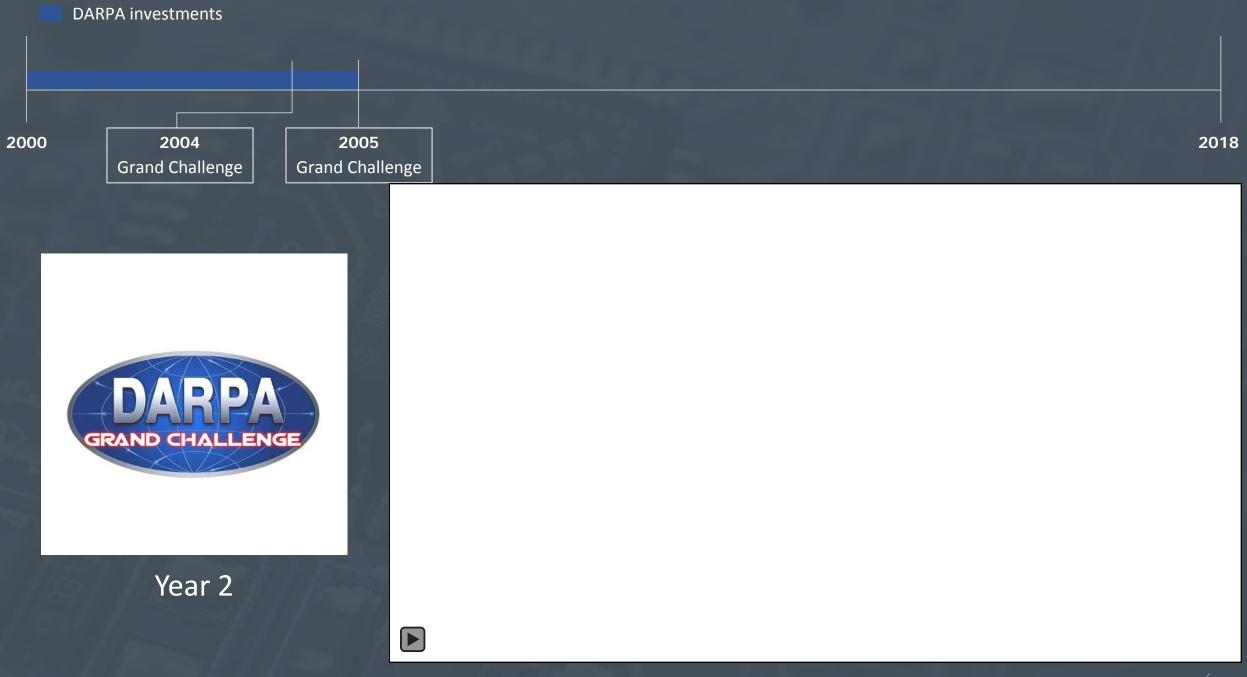
CLOUD

ARTIFICIAL INTELLIGENCE

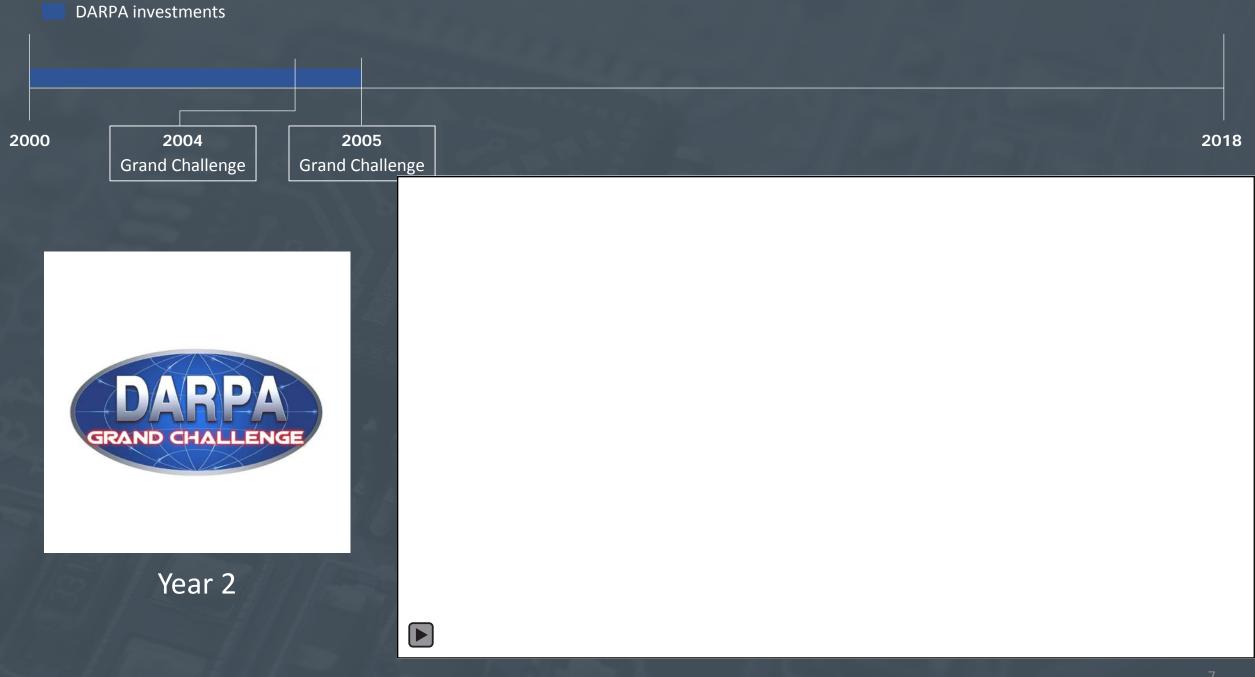


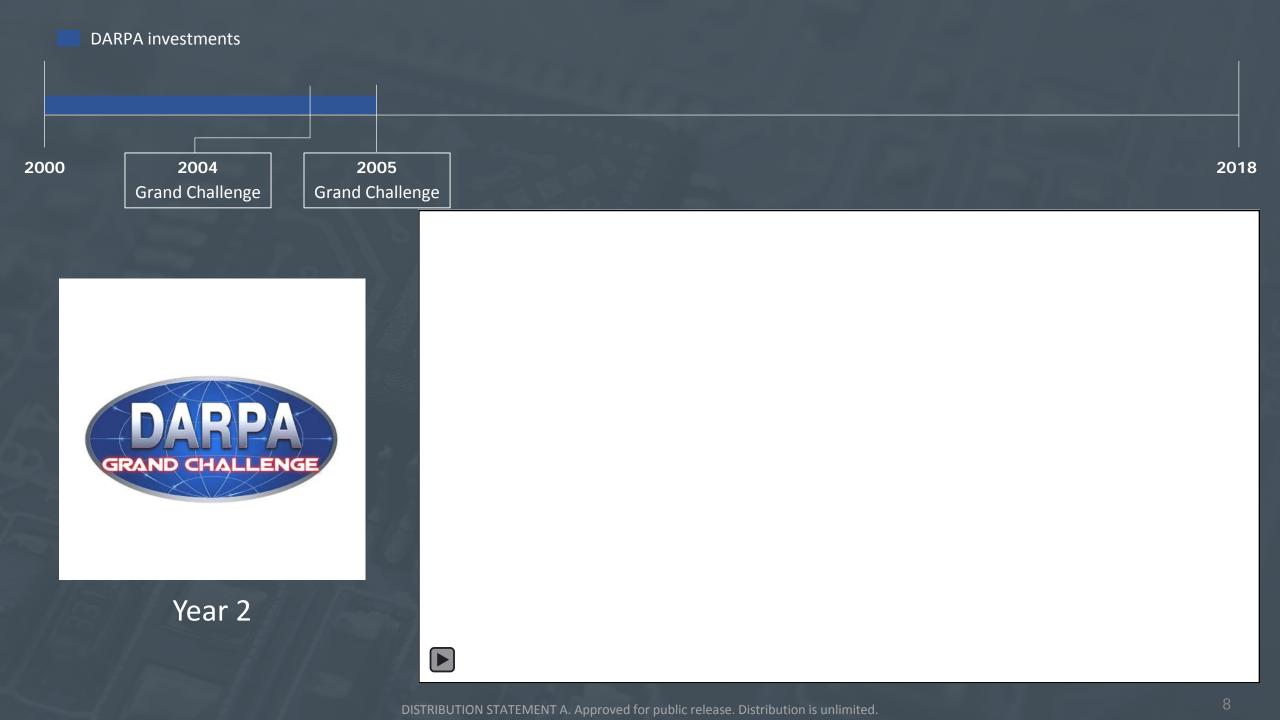






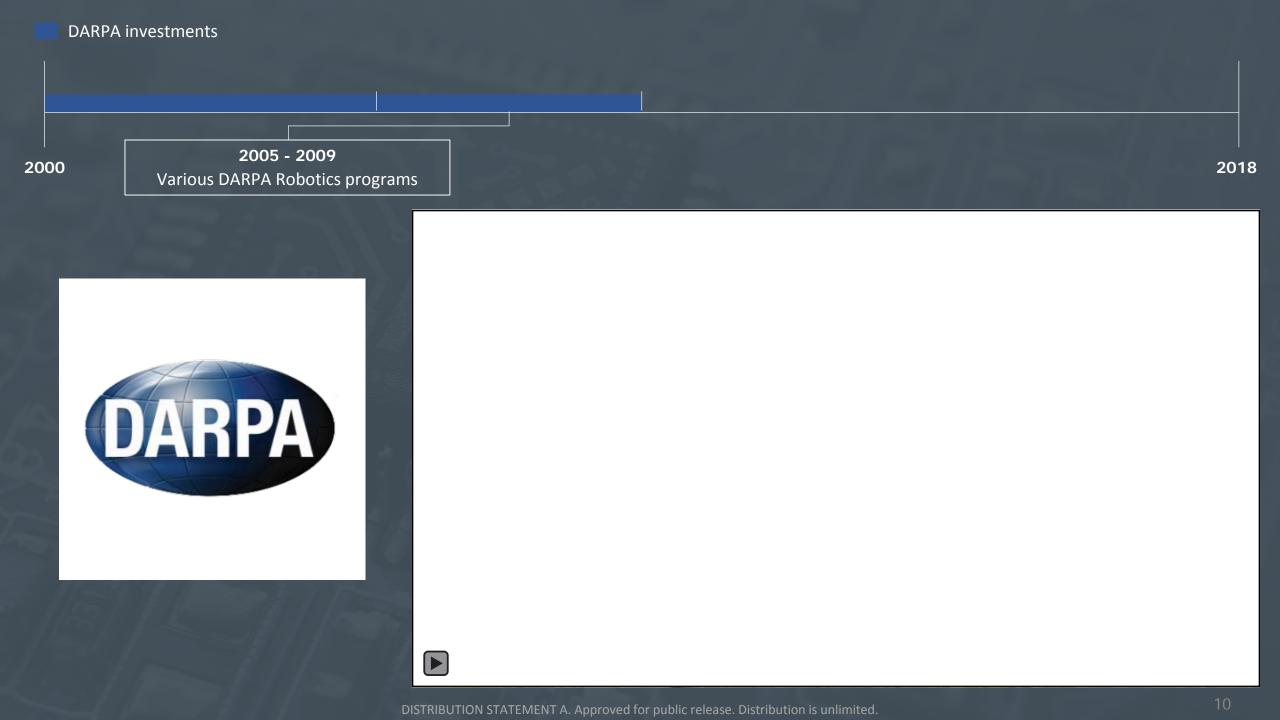
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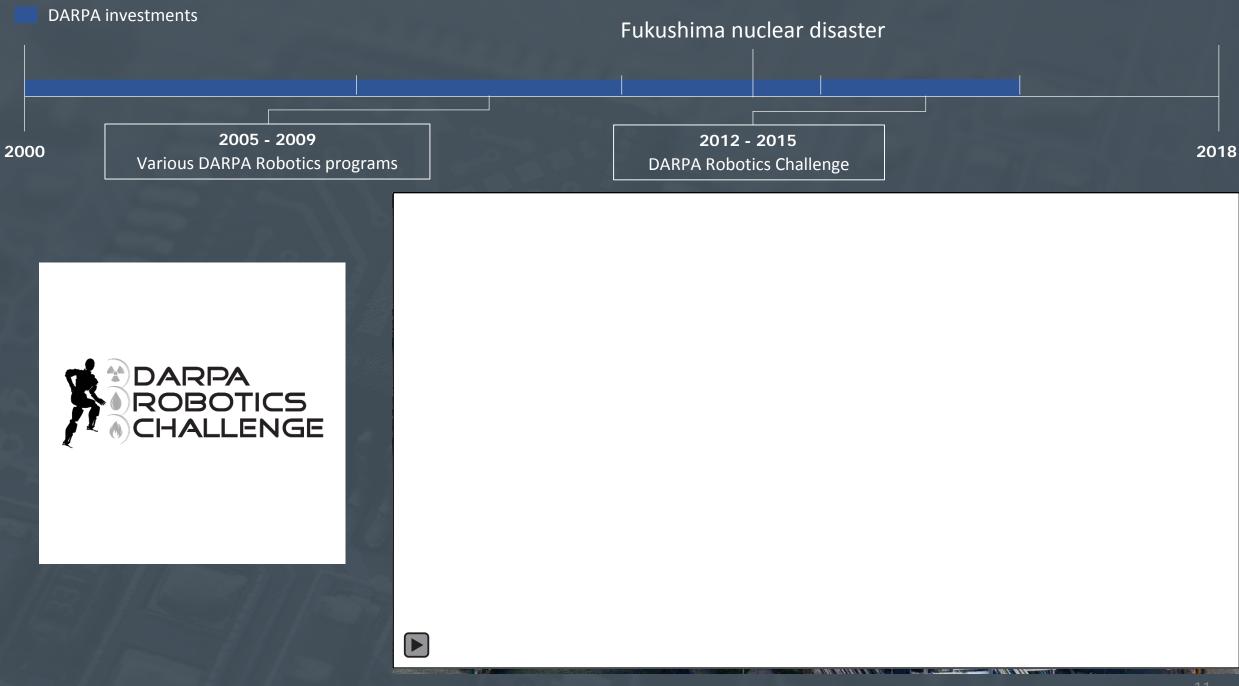


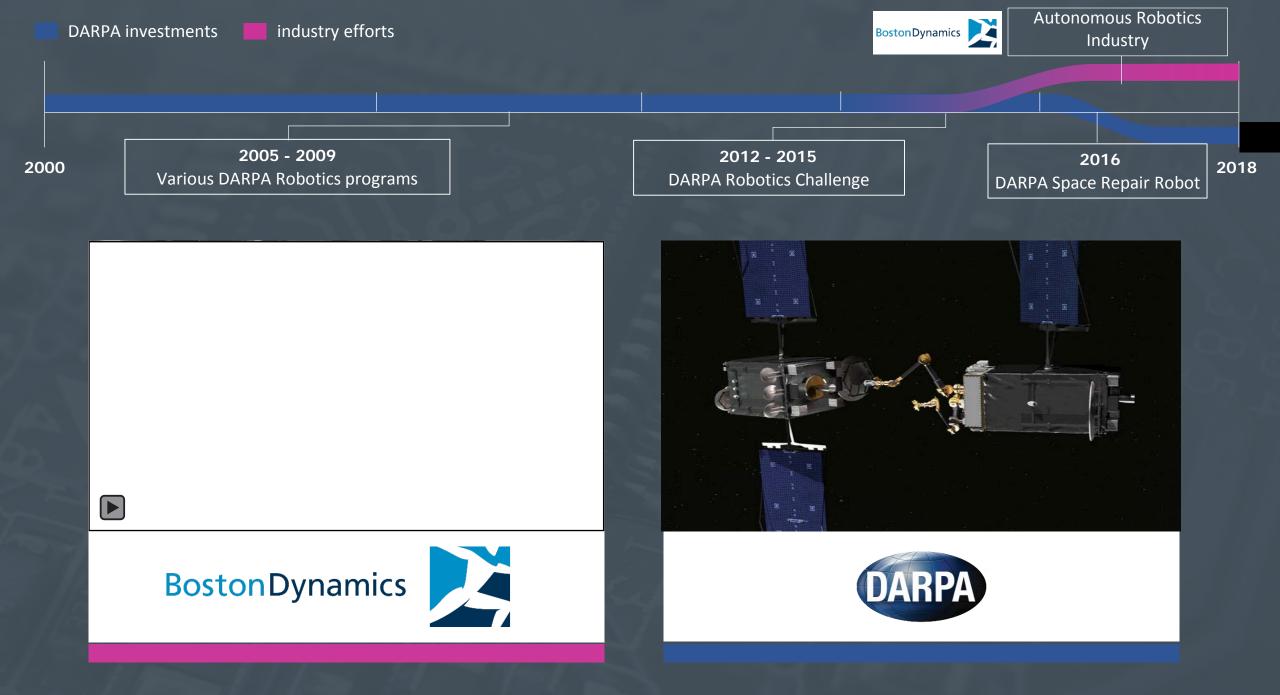


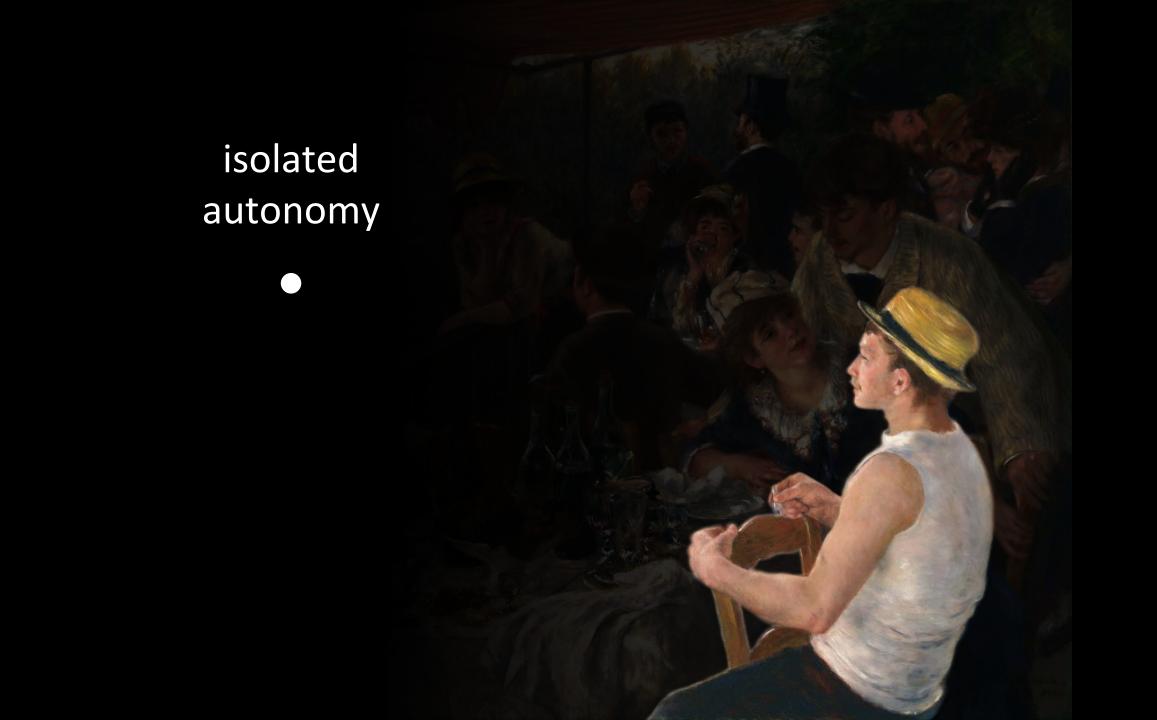


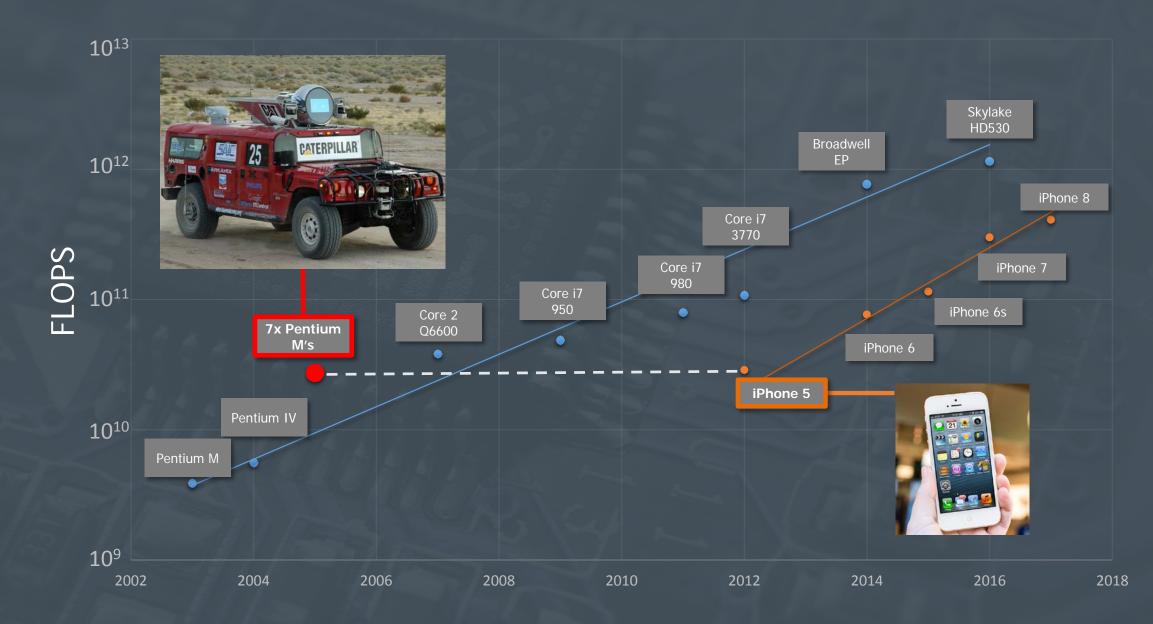






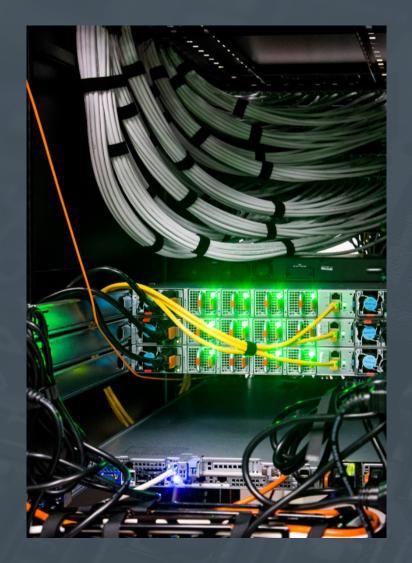






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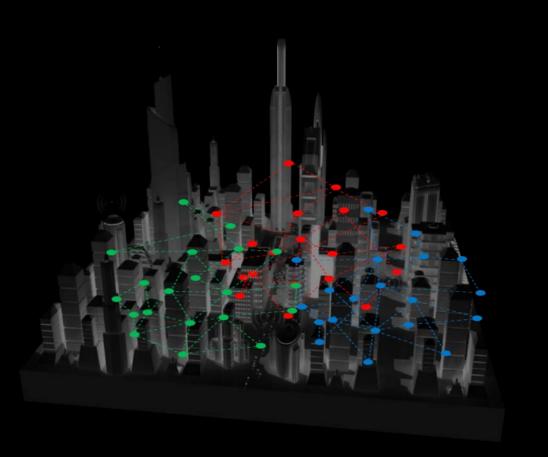


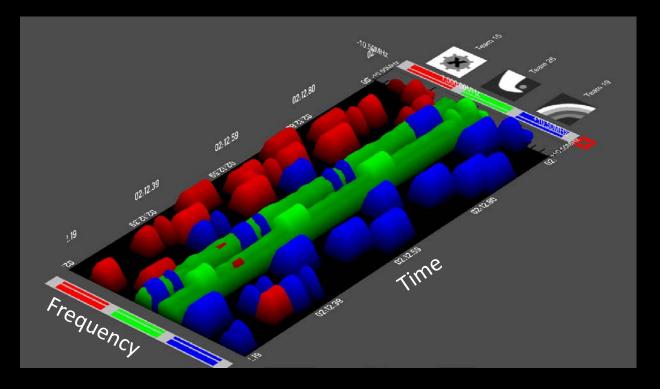






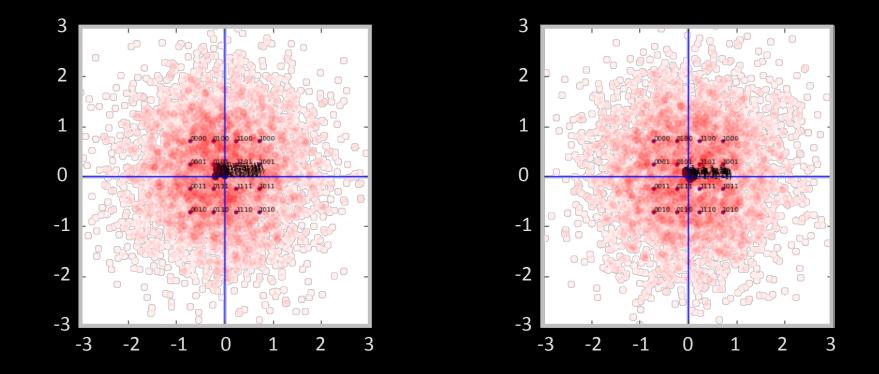
SPECTRUM COLLABORATION CHALLENGE

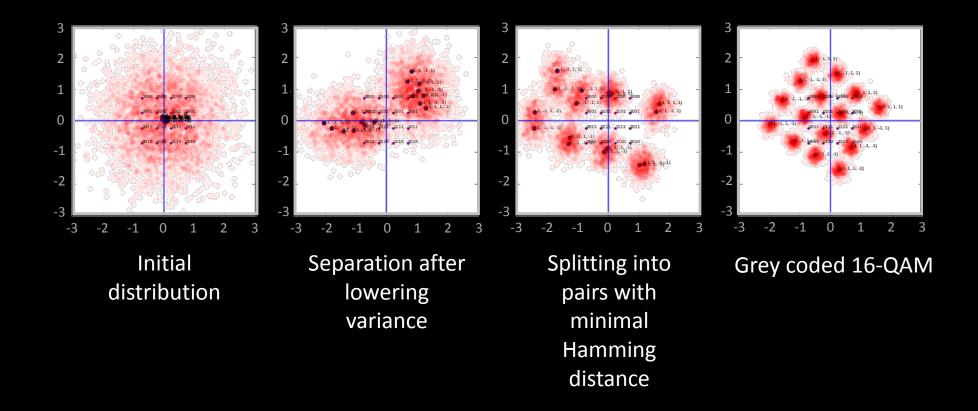




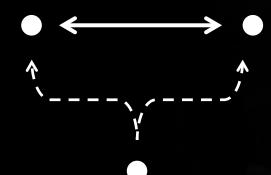
## 1-1 communication

 $\bullet \leftarrow --- \rightarrow \bullet$ 





## observer communication



# The Good



# The Bad

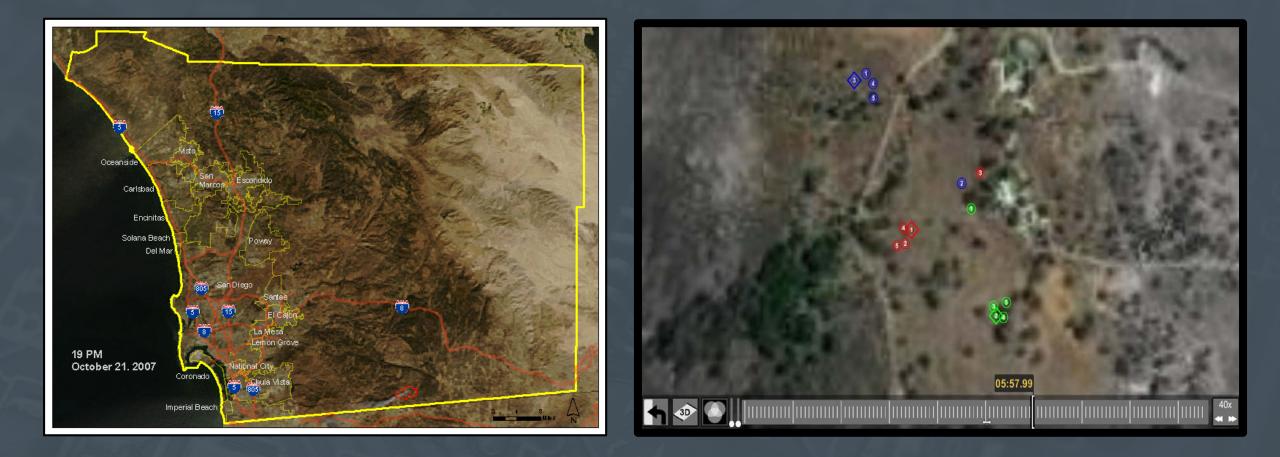


# The Ugly



## a collection of learned systems

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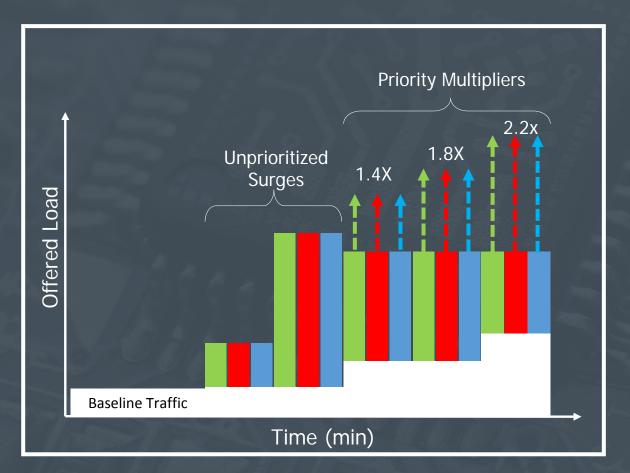
# The Good

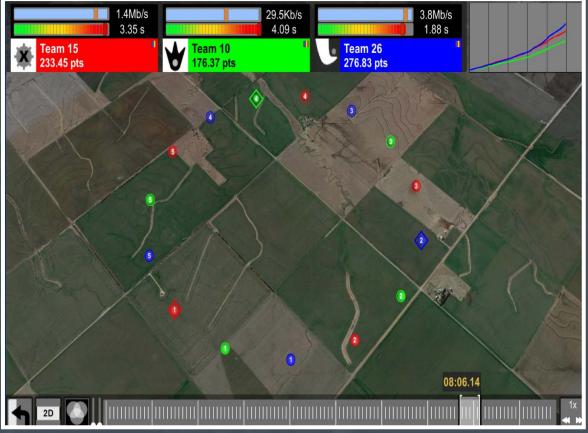


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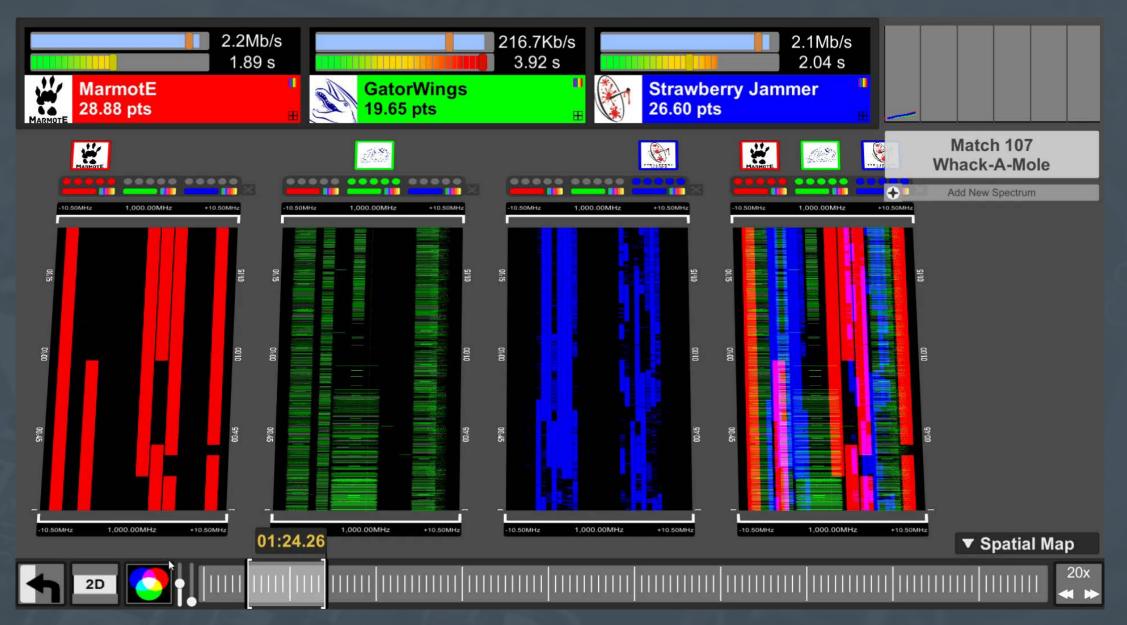
# The Role of the Human: San Diego Wildfire

Туре	Priority	Rate (kbps)	Timing
Control Traffic	1.8	10	Continuous
VOIP	1.6	32.4	Continuous
Imagery (FTP)	1.4	419.4	Once every 20 seconds
Video Buffer	1.2	83.2	Continuous
Video Stream	1.2	750	Continuous
PLI	1.0	0.4	Continuous





# The Bad



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### Autonomous Intersection Management (AIM) Project

Department of Computer Sciences University of Texas at Austin

> Project Members: Prof. Peter Stone Dr. Guni Sharon Dr. Michael Albert Josiah Hanna

### Open loop autonomy (requires rules)

OK for light traffic...doesn't scale with congestion/demand

### Collaboration and autonomy

Scaling to meet congestion/demand



#### **DARPA** investments

Year 1

### 2000

### 2004 Grand Challenge

2012

### SC2 PE-1 Tournament

Not one team used the available FPGA or GPU successfully as a differentiator 2030

2018

THE FUTURE OF COMPUTING PERFORMANCE

APPENDIX C

IV. COSTS AND CURVES

a the technology evolves toward the production of

### Cramming More Components onto **Integrated Circuits**

GORDON E. MOORE, LIFE FELLOW, IEEE

170

With unit cost falling as the number of components per circuit rises, by 1975 economies may dictate squeezing as many as 65 000 components on a single silicon chip.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers-or at least terminals connected to a central computer-automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today. But the biggest potential lies in the production of large

systems. In telephone communications, integrated circuits in digital filters will separate channels on multiplex equipment. Integrated circuits will also switch telephone circuits and perform data processing.

Computers will be more powerful, and will be organized in completely different ways. For example, memories built of integrated electronics may be distributed throughout the machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with faster turnaround.

#### I. PRESENT AND FUTURE

By integrated electronics, I mean all the various technologies which are referred to as microelectronics today as well as any additional ones that result in electronics functions supplied to the user as irreducible units. These technologies were first investigated in the late 1950's. The object was to miniaturize electronics equipment to include increasingly complex electronic functions in limited space with minimum weight. Several approaches evolved, including microassembly techniques for individual components, thin-film structures, and semiconductor integrated circuits.

Reprinted from Gordon E. Moere, "Cramming More Components onto Integrated Circuits," *Electronics*, pp. 114–117, April 19, 1965. Publisher Item Identifier S 0018-9219(98)00753-1.

Each approach evolved rapidly and converged so that each borrowed techniques from another. Many researchers believe the way of the future to be a combination of the various approaches. The advocates of semiconductor integrated circuitry are

already using the improved characteristics of thin-film resistors by applying such films directly to an active semiconductor substrate. Those advocating a technology based upon films are developing sophisticated techniques for the attachment of active semiconductor devices to the passive film arrays.

Both approaches have worked well and are being used in equipment today.

#### II. THE ESTABLISHMENT

Integrated electronics is established today. Its techniques are almost mandatory for new military systems, since the reliability, size, and weight required by some of them is achievable only with integration. Such programs as Apollo, for manned moon flight, have demonstrated the reliability of integrated electronics by showing that complete circuit functions are as free from failure as the best individual transistors.

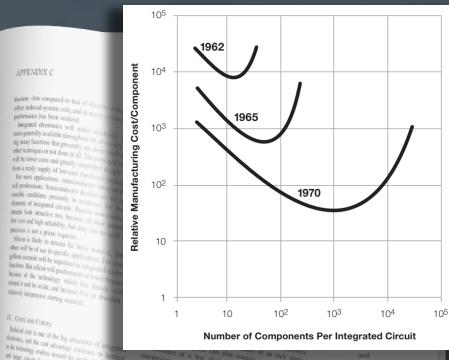
Most companies in the commercial computer field have machines in design or in early production employing integrated electronies. These machines cost less and perform better than those which use "conventional" electronics. Instruments of various sorts, especially the rapidly increasing numbers employing digital techniques, are starting to use integration because it cuts costs of both manufacture and design.

The use of linear integrated circuitry is still restricted primarily to the military. Such integrated functions are expensive and not available in the variety required to satisfy a major fraction of linear electronics. But the first applications are beginning to appear in commercial electronics, particularly in equipment which needs low-frequency amplifiers of small size

#### III. RELIABILITY COUNTS

In almost every case, integrated electronics has demonstrated high reliability. Even at the present level of pro-

PROCEEDINGS OF THE HEE, VOL. 86, NO. 1, JANUARY 1998



#### Number of Components Per Integrated Circuit

ad layer circuit functions on a single semiconductor inch. Thus, 65 000 components need occupy only about a per finear inch or a quarter million per square where For simple circuits, the cost per component is tedy inercely propertional to the number of components, one-fourth a square inch. the mak of the equivalent piece of semiconductor in On the silicon wafer currently used, usually an inch or the equivalent puckage containing more components. But more in diameter, there is ample room for such a structure if a oppress are added, decreased yields more than the components can be closely packed with no space wasted composate for the increased complexity, tending to raise for interconnection patterns. This is realistic, since efforts to achieve a level of complexity above the presently available de aut per component. Thus there is a minimum cost integrated circuits are already under way using multilayer it say pier time in the evolution of the technology. At metallization patterns separated by dielectric films, Such a proof it is nached when 50 components are used per density of components can be achieved by present optical that Ba the minimum is rising rapidly while the entire techniques and does not require the more exotic techniques. or one is falling (see graph). If we look ahead five such as electron beam operations, which are being studied Jun, a pix of costs apgests that the minimum cost per

oppace night be expected in circuits with about 1000 papages per circuit (providing such circuit functions in k pulsed in moderate quantities). In 1970, the VI. INCREASING THE YIELD tradacting cost per component can be expected to be

considerations make such arrays desirable.

There is no fundamental obstacle to achieving device yields of 100%. At present, packaging costs so far exceed The complexity for minimum component costs has inthe cost of the semiconductor structure itself that there is no eased as the of mighty a factor of two per year incentive to improve yields, but they can be raised as high bu put Centraly over the short term this rate can be as is economically justified. No barrier exists comparable excited to catting, if not to increase. Over the longer to the thermodynamic equilibrium considerations that often en te sar of increase is a bit more uncertain, although limit yields in chemical reactions; it is not even necessary be it in reason to believe it will not remain nearly to do any fundamental research or to replace present then for stress to believe it with not remain manage stress of it has the year. That means by 1975, the processes. Only the engineering effort is needed. the adverter of the second sec In the early days of integrated circuitry, when yields were extremely low, there was such incentive. Today ordinary have the rule a large circuit can be built on a single integrated circuits are made with yields comparable with those obtained for individual semiconductor devices. The same pattern will make larger arrays economical, if other

feedback 11 fraction lators with aded in the increasingly components d will allow at the lower present time wave area by realization of ample, using a

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### P.3

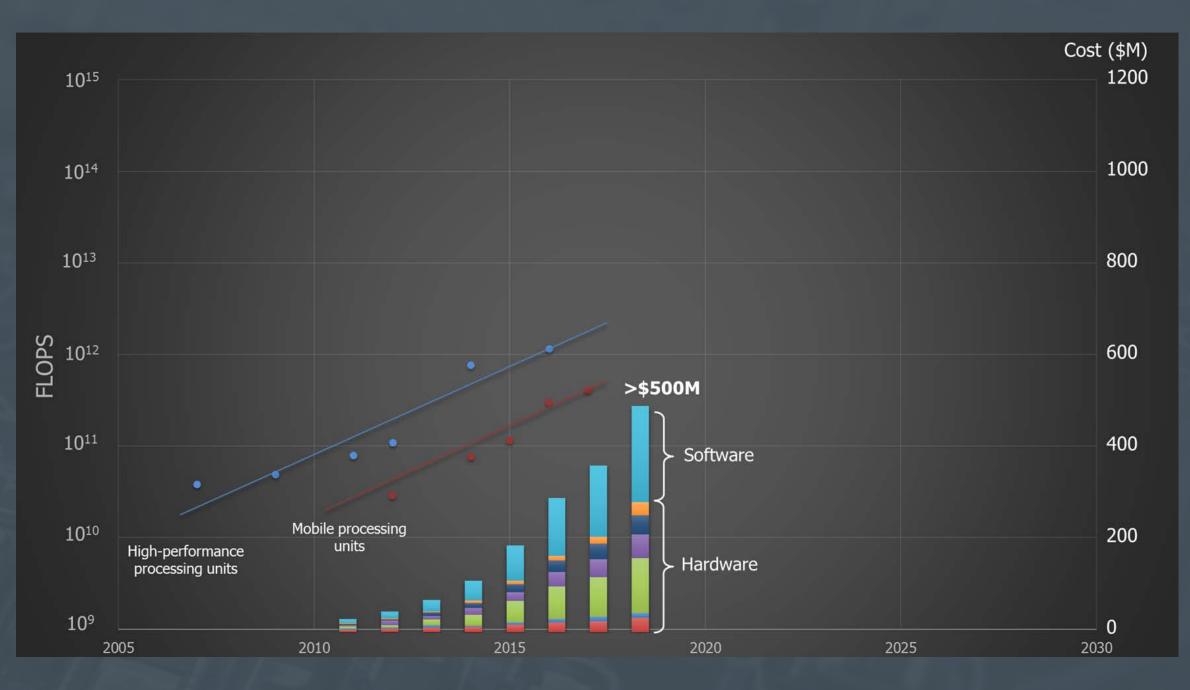
Electronics, April 19, 1965: Cramming More Components onto Integrated Circuits; Gordon Moore

> Today "component-crammed equipment"

### VIII. DAY OF RECKONING

Clearly, we will be able to build such component-crammed equipment. Next, we ask under what circumstances we should do it. The total cost of making a particular system function must be minimized. To do so, we could amortize the engineering over several identical items, or evolve flexible techniques for the engineering of large functions so that no disproportionate expense need be borne by a particular array. Perhaps newly devised design automation procedures could translate from logic diagram to technological realization without any special engineering.

It may prove to be more economical to build large systems out of smaller functions, which are separately packaged and interconnected. The availability of large functions, combined with functional design and construction, should allow the manufacturer of large systems to design and construct a considerable variety of equipment both rapidly and economically.



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# **COMPLEXITY BIND**

Cost

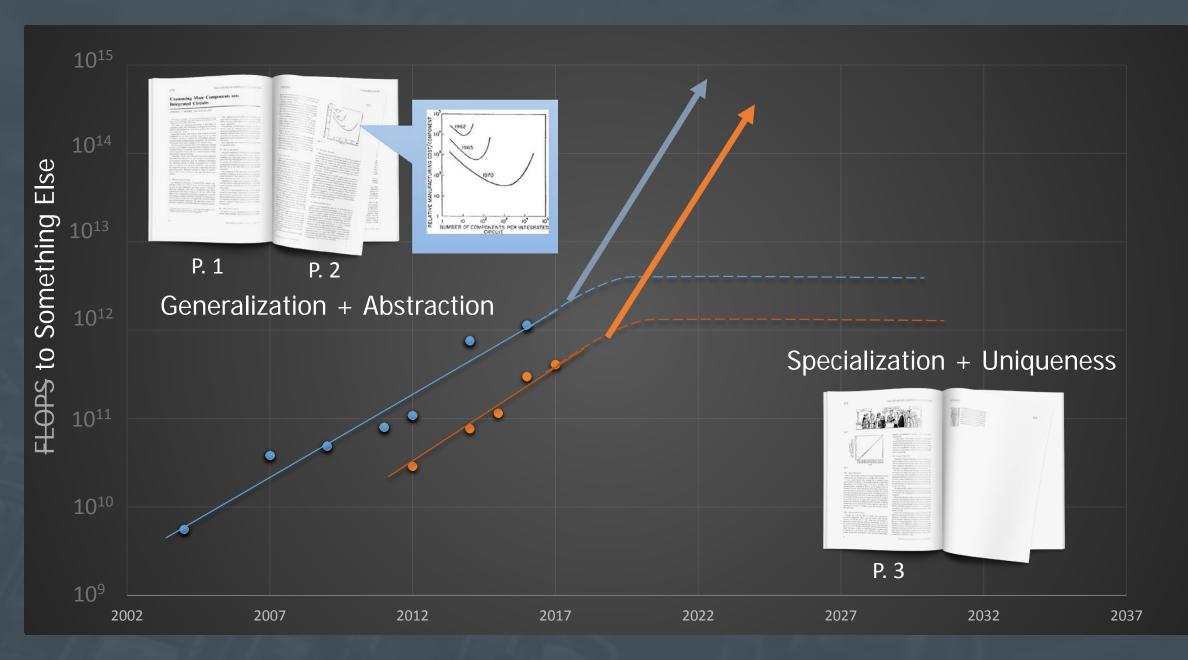
Abstraction

The cost of integrated circuit fabrication, design, and verification is skyrocketing, limiting innovation

The continued move towards generalization and abstraction is stifling potential gains in hardware

Foreign Investments Foreign investments are distorting the market and driving a shift outside of the U.S.

Rising Stakes Digital influence is so pervasive in our society that we can't afford to have flaws in the digital foundation



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#### **Designs** Quickly enabling specialization

Designs Thrust

- 52 // calculate products as in \* tap
- 53 val products = DspContext.withTrimType(dsptools.NoTrim) {
- 54 io.taps.reverse.map { tap => in.map { i =>
- 55 ShiftRegister(i \* tap, config.multiplyPipelineDepth)
- 56 }}

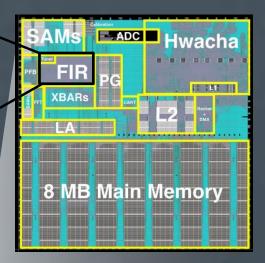


# Serial 512KB Strial 512KB Maintor Crossbar Tock for Crossbar Unit Morridon Morridon Morridon Serial 512KB Strial 512KB Maintor Crossbar Crossbar Crossbar Control Crossbar Crossbar DBP Accelerator to XM Data Control Crossbar Consbar Constant Consbar Constant Crossbar Constant Consbar Constant </

Image: UC Berkeley CRAFT

#### CRAFT

"Perhaps newly devised design automation procedures could translate from logic diagram to technological realization without any special engineering"



# GitHub

// calculate products as in \* tap wal products = Daptentest.valchristype(dapteols.terristy); is.tupp.reverse.sep { lag => ir.sep { l => Stiftingister(i \* tap, config.enthiplyPipeliesDepth) }))

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CAPTAIN TSUBASA Tumblr.com IAMAG Published on Nov 14, 2016 More on http://www.iamag.c

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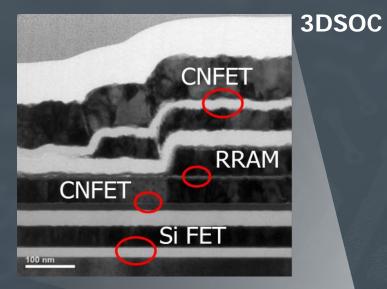
# Quickly enabling specialization

#### Materials & Integration

Adding separately packaged novel materials and using integration to provide specialized computing



## **Materials & Integration Thrust**



Images: Stanford, MIT

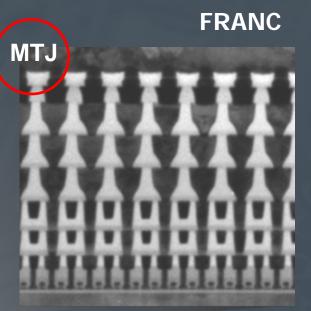


Image: GLOBALFOUNDRIES

### CHIPS

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**Architectures** Maximizing specialized functions

#### **Designs** Quickly enabling specialization

#### Materials & Integration

Adding separately packaged novel materials and using integration to provide specialized computing



HIVE

**SDH** 

## **Architectures Thrust**

#### Array of sensors

"...amortize the engineering over several

for the engineering of large functions..."

*identical items, or evolve flexible techniques* 

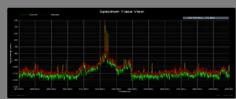
DSSoC

HIVE

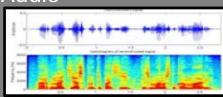
#### LIDAR



#### RF



#### Audio



#### Image: Drexel Univ.



YEAR Fig. 3.

#### VII. HEAT PROBLEM

Will it be possible to remove the heat generated by tens of thousands of components in a single silicon chip?

If we could shrink the volume of a standard highspeed digital computer to that required for the components themselves, we would expect it to glow brightly with present power dissipation. But it won't happen with integrated circuits. Since integrated electronic structures are two dimensional, they have a surface available for cooling close to each center of heat generation. In addition, power is needed primarily to drive the various lines and capacitances associated with the system. As long as a function is confined to a small area on a wafer, the amount of capacitance which must be driven is distinctly limited. In fact, shrinking dimensions on an integrated structure makes it possible to operate the structure at higher speed for the same pop per unit area.

#### VIII. DAY OF RECKONING

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It may prove to be mo. systems out of smaller functions, which are separately packaged and interconnected. The availability of large functions. combined with functional design and construction, should allow the manufacturer of large systems to design and construct a considerable variety of equipment both rapidly and economically.

#### IX. LINEAR CIRCUITRY

Integration will not change linear systems as radically as digital systems. Still, a considerable degree of integration will be achieved with linear circuits. The lack of largevalue capacitors and inductors is the greatest fundamental limitation to integrated electronics in the linear area. By their very nature, such elements require the storage of energy in a volume. For high Q it is necessary that the volume be large. The incompatibility of large volume and integrated electronics is obvious from the terms themselves. Certain resonance phenomena, such as those in piezoeleetric crystals, can be expected to have some applications for tuning functions, but inductors and capacitors will be with us for some time.

The integrated RF amplifier of the future might well of sist of integrated stages of gain, giving high perform at minimum cost, interspersed with relatively large

Other linear functions will be changed consider matching and tracking of similar components in i structures will allow the design of differential a greatly improved performance. The use of them effects to stabilize integrated stru-

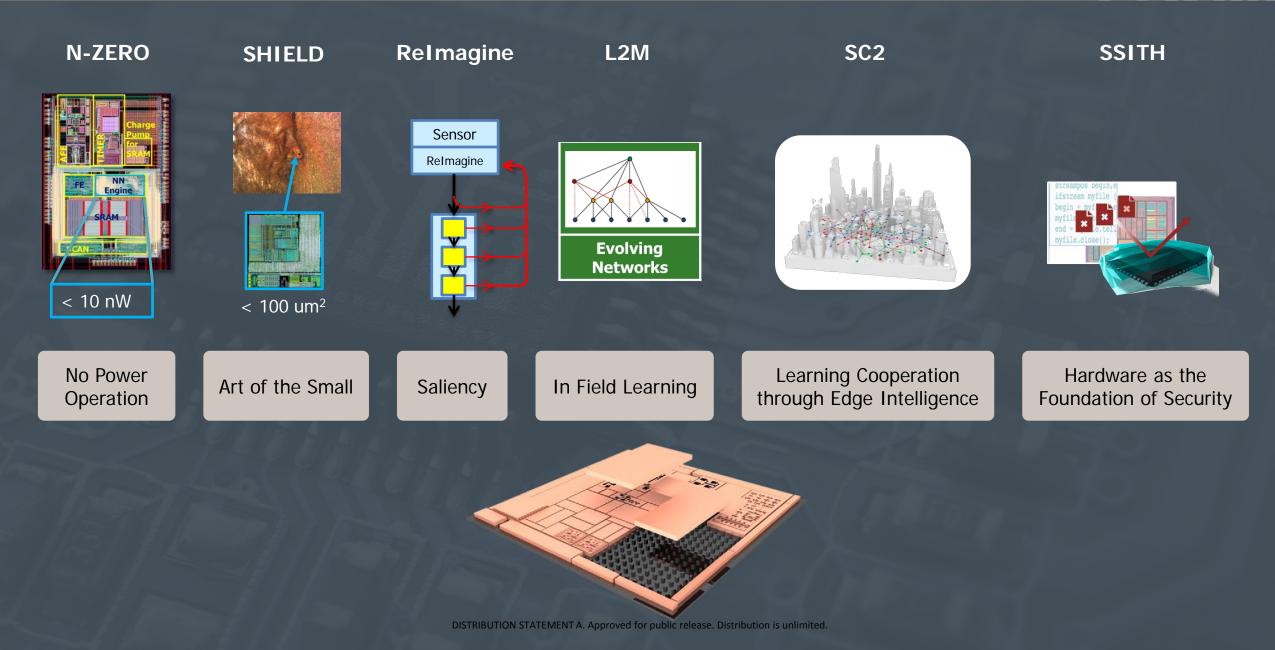
Even in the microwave area, structures included in the definition of integrated electronics will been important. The ability to make and assemb small compared with the wavelengths involved will all the use of lumped parameter design, at least at the low frequencies. It is difficult to predict at the present time just how extensive the invasion of the microwave area t integrated electronics will be. The successful realization such items as phased-array antennas, for example, using t multiplicity of integrated microwave power sources, could completely revolutionize radar.

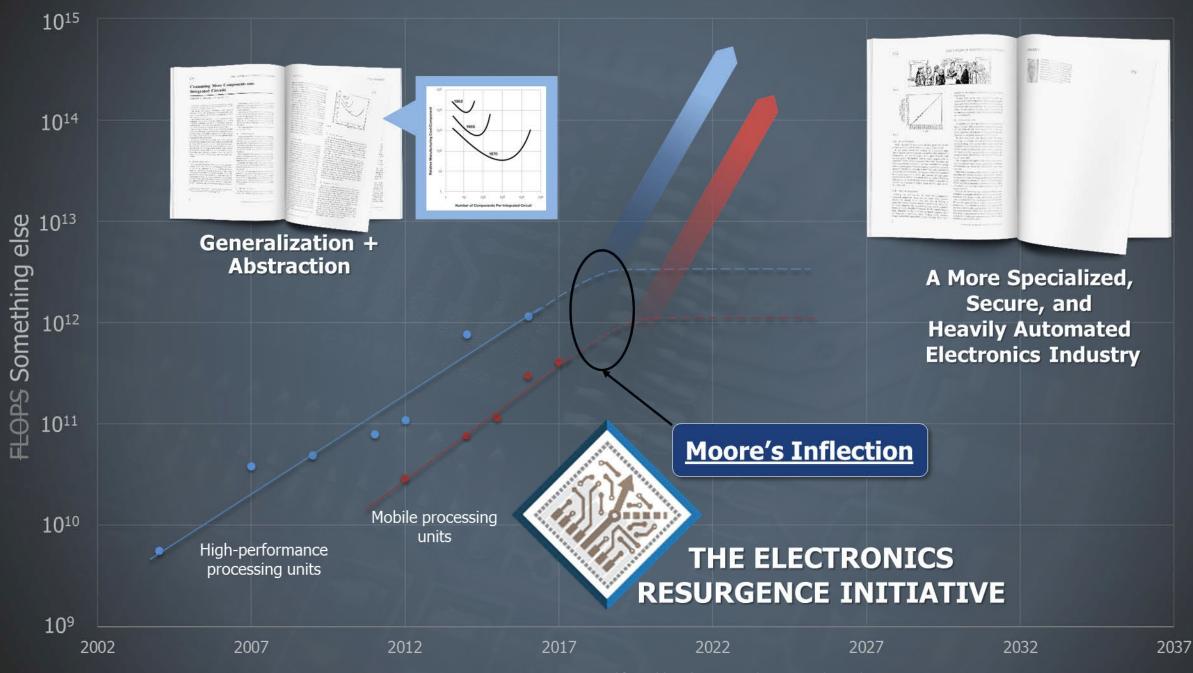
APPENDIX C 173

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## **Driving Applications**

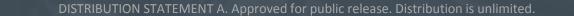


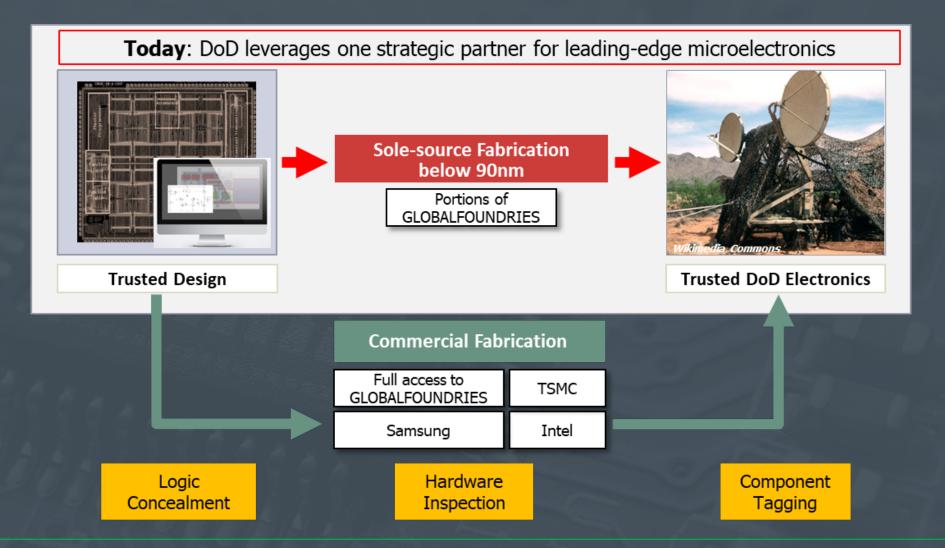


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**Tomorrow**: Technology-driven security techniques enable additional options for acquiring state-of-the-art, commercial microelectronics, based on each DoD program's need