DOES BRITAIN NEED A “DARPA” ?

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Technology Strategy Board

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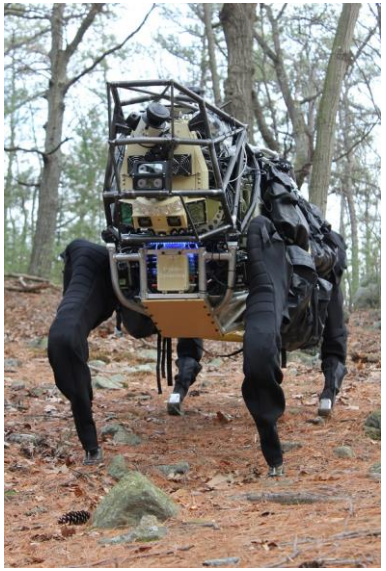
STRUCTURE OF PRESENTATION

1. DARPA

1. RELATIONSHIP TO BROADER US INNOVATION SYSTEM

1. WOULD A UK DARPA ADDRESS THE POLICY CHALLENGE ?



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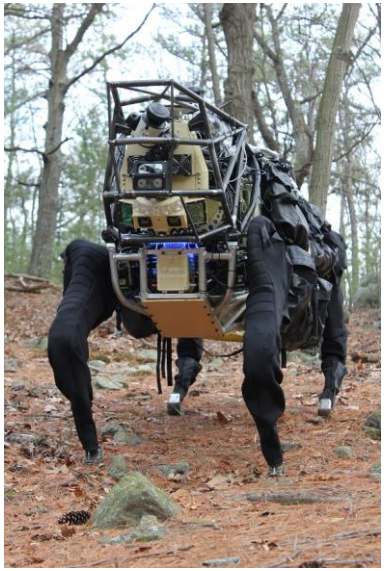


DARPA – The Basics (1)

- Formed as ‘ARPA’ in 1958 in response to Sputnik 1
- Known as DARPA (Defence Advanced Research Projects Agency) for all but 3 years since 1972.
- Key early roles in development of GPS (‘TRANSIT’), internet (‘ARPANET’ wide area packet switching), network firewalls, ‘stealth’ technologies, UAVs.
- Wide range of technologies supported at different times – materials, semiconductor and photonics components, behavioural science, medial technology, aerospace vehicles, sensors, computing, systems.
- Attempts to replicate model in other Federal agencies.

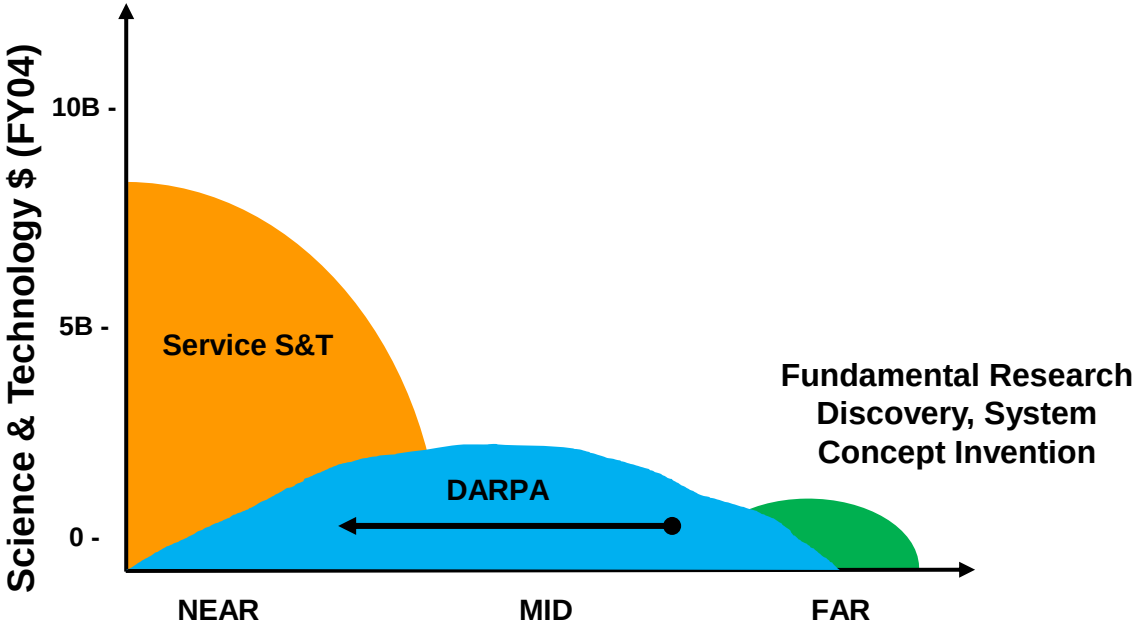
DARPA – The Basics (2)

- Annual expenditure $2.8 billion
  - Companies
  - Universities
  - Not for Profit Labs
- Operates mainly through contracts with some prize-based ‘challenge’ competitions
- 120 technical programme managers, 240 staff overall
- No laboratory facilities
- Uses other Department of Defense R&D Laboratories and R&D managers to support project specification and management
- Projects designed to deliver technology of relevance to branches of DoD

DARPA Mission Today

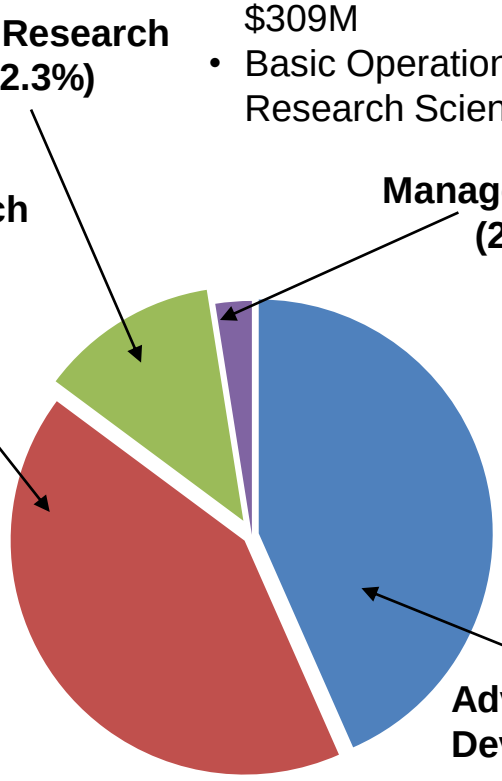
"…to **prevent strategic surprise** from negatively impacting US national security and **create strategic surprise** for US adversaries by maintaining the technological superiority of the US Military"

... "DoD's primary innovation engine"



Timelines and investments in science and technology

DARPA Budget 2012/13



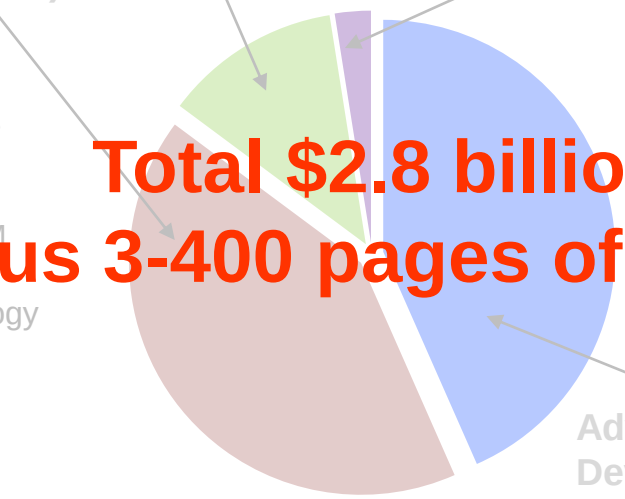
- Defense Research Sciences $309M
- Basic Operational Medical Research Science $40M

- Biomedical technology $111M
- Information and Communications Technology $392M
- Cognitive computing $30M
- Biological Warfare Defense $19M
- Tactical Technology $233M
- Materials and Biological Technology $166M
- Electronics Technology $222M

Approx. $70M spend through SBIR/STTR process

- Advanced Aerospace Systems $174M
- Space Programs and Technology $159M
- Advanced Electronics $111M
- Command, Control and Communications Systems $238M
- Classified $3M
- Network – centric warfare technology $237M
- Sensor technology $299M

DARPA Budget 2012/13



Basic Research (12.3%)

- Defense Research Sciences $309M
- Basic Operational Medical Research Science $40M

Management HQ (2.5%)

- Approx. $70M spend through SBIR/STTR process

Applied Research (41.7%)

- Biomedical technology $111M
- Information and Communications Technology $392M
- Cognitive computing $30M
- Biological Warfare Defense $19M
- Tactical Technology $233M
- Materials and Biological Technology $166M
- Electronics Technology $222M

Total $2.8 billion

Plus 3-400 pages of detail

Advanced Technology Development (43.3%)

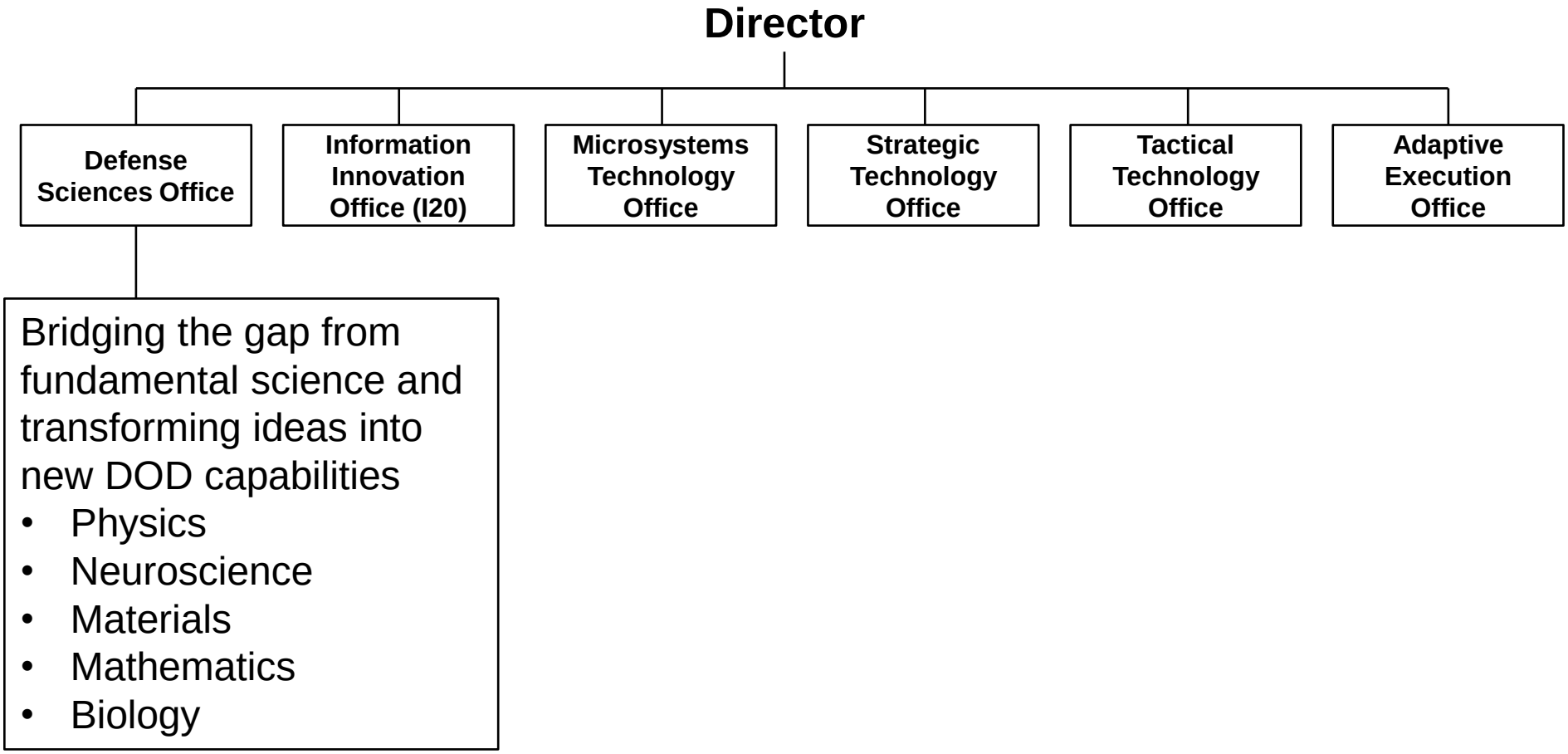
- Advanced Aerospace Systems $174M
- Space Programs and Technology $159M
- Advanced Electronics $111M
- Command, Control and Communications Systems $238M
- Classified $3M
- Network – centric warfare technology $237M
- Sensor technology $299M

Page 71 of DARPA Budget

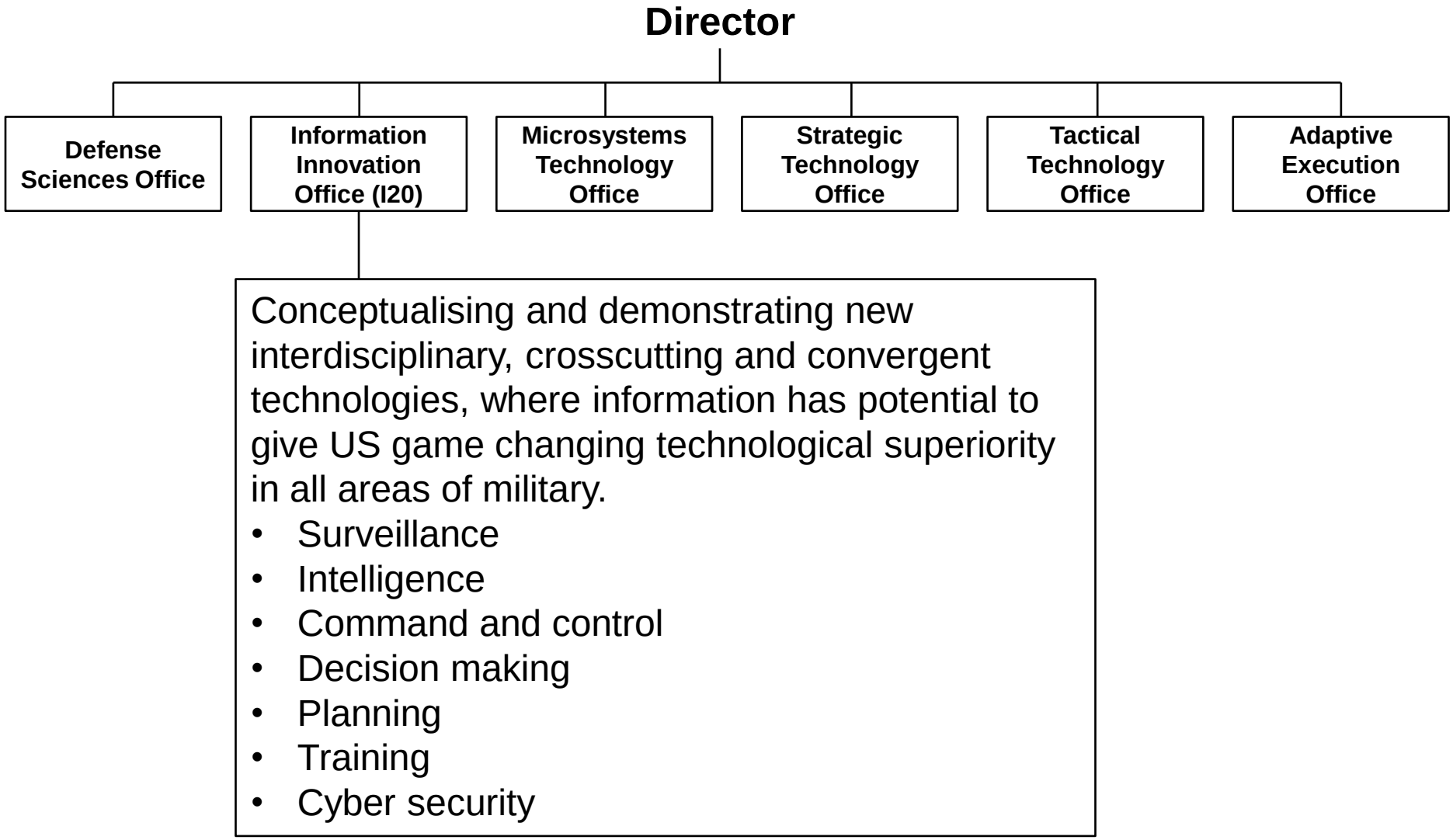
Exhibit R-2, RDT&E Budget Item Justification: PB 2013 Defense Advanced Research Projects Agency	DATE: February 2012
APPROPRIATION/BUDGET ACTIVITY 0400: *Research, Development, Test & Evaluation, Defense-Wide* BA 1: *Basic Research*	R-1 ITEM NOMENCLATURE PE 0601117E: *BASIC OPERATIONAL MEDICAL SCIENCE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2011	FY 2012	FY 2013
- Demonstrate the ability of non-human primates to perform a dexterous sensorimotor task through the use of a neural interface, without the use of neural spike recordings.			
Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT)* ***Description:*** *Previously funded in Synthetic Biology in PE 0601101E, Project TRS-01 The Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program will develop the underlying technologies to rapidly respond to a disease or threat, and improve individual readiness and total force health protection by providing centralized laboratory capabilities at non-tertiary care and individual settings. ADEPT will develop and exploit synthetic biology for the in vivo creation of nucleic acid circuits that continuously and autonomously sense and respond to changes in physiologic state and for novel methods to target delivery, enhance immunogenicity, or control activity of vaccines, potentially eliminating the time to manufacture a vaccine ex vivo. ADEPT advancements to control cellular machinery include research to optimize orthogonality and modularity of genetic control elements; identify methods to increase sensitivity and specificity; and demonstrate methods to control cellular machinery in response to changes in physiological status. ADEPT will develop methodologies for measuring health-specific biomarkers from a collected biospecimen to enable diagnostics at the point-of-need or resource limited clinical facilities (point-of-care), in-garrison or deployed. Additionally, ADEPT will initiate techniques to characterize natural signal transduction pathways, such as electrical and mechanical, that are not conventionally used to guide diagnosis, or as a therapeutic measure. The signals will be studied in detail and their physiological function validated for measurement and modulation to determine diagnostic and therapeutic benefit. Applied research efforts are budgeted in PE 0602115E, Project BT-01. ***FY 2012 Plans:*** - Initiate development of modular and orthogonal nucleic acid-based elements for application within a sense-and-respond circuit that operates within context of a mammalian cell. - Investigate controlled expression in mammalian cells of synthetic circuit that responds to physiological biomarkers associated with health status. - Develop novel concepts and molecular approaches to enable deployable diagnostics. - Develop novel reagents and materials for stabilizing self-collected biospecimens at room temperature for simple shipment and storage. - Develop methods for sample preparation that require no operator manipulation and are consistent with point-of-need and point-of-care settings. - Develop new methods for signal amplification amenable to deployable diagnostics. ***FY 2013 Plans:*** - Demonstrate development of modular and orthogonal nucleic acid-based elements for application within a sense-and-respond circuit that operates within context of a mammalian cell.	-	17.500	24.500

DARPA Structure



DARPA Structure



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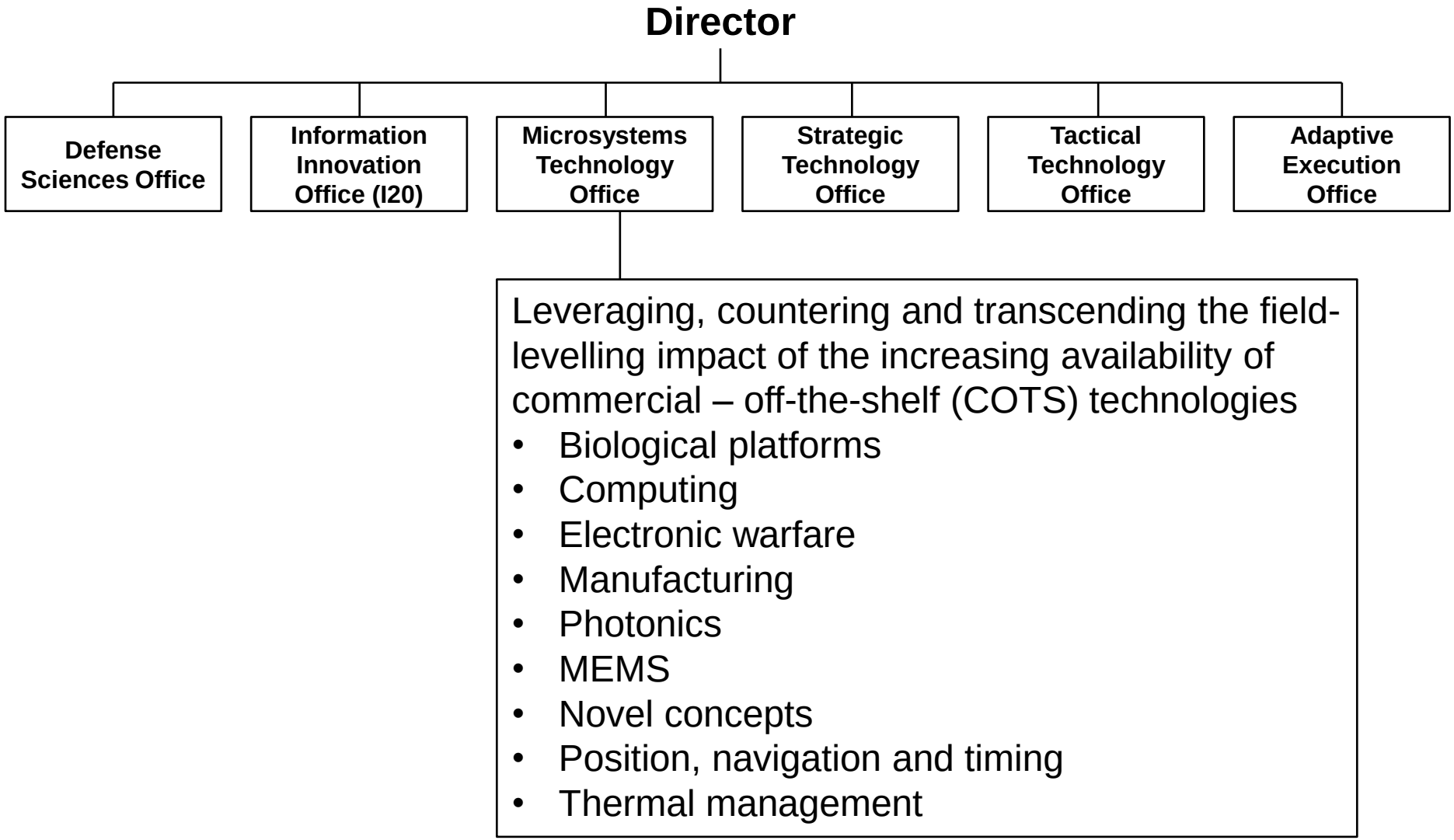

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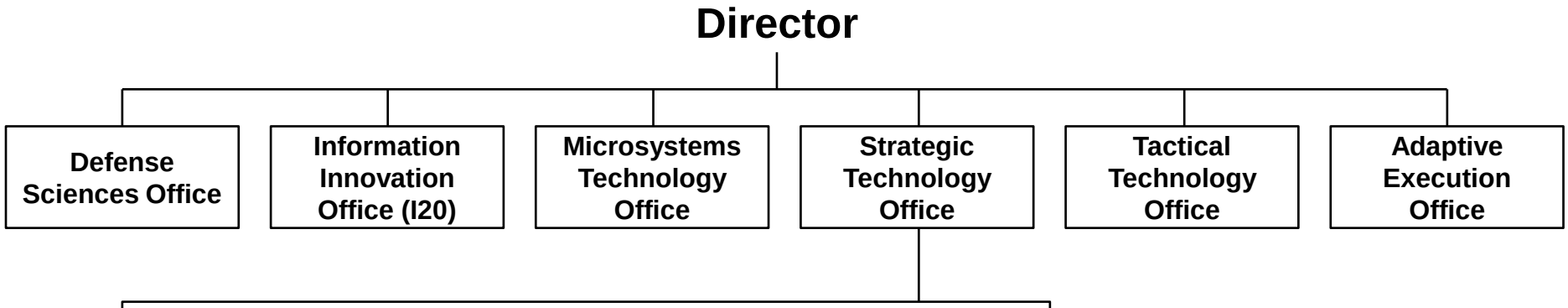
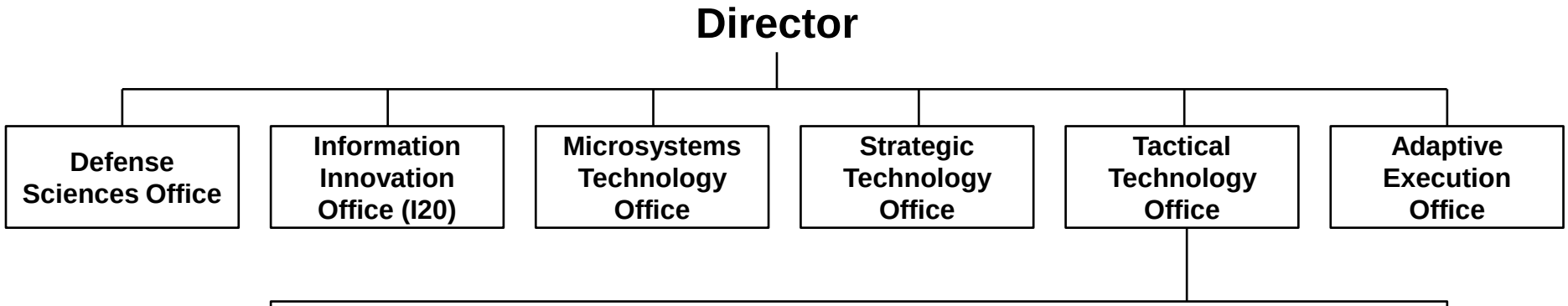


Current and emerging strategic areas:

- Finding difficult targets
- Communications, networks and electronic warfare
- Shaping the environment
- “Foundational strategic technologies”
- PLATFORMS, WEAPONS, SPACE SYSTEMS

DARPA Structure

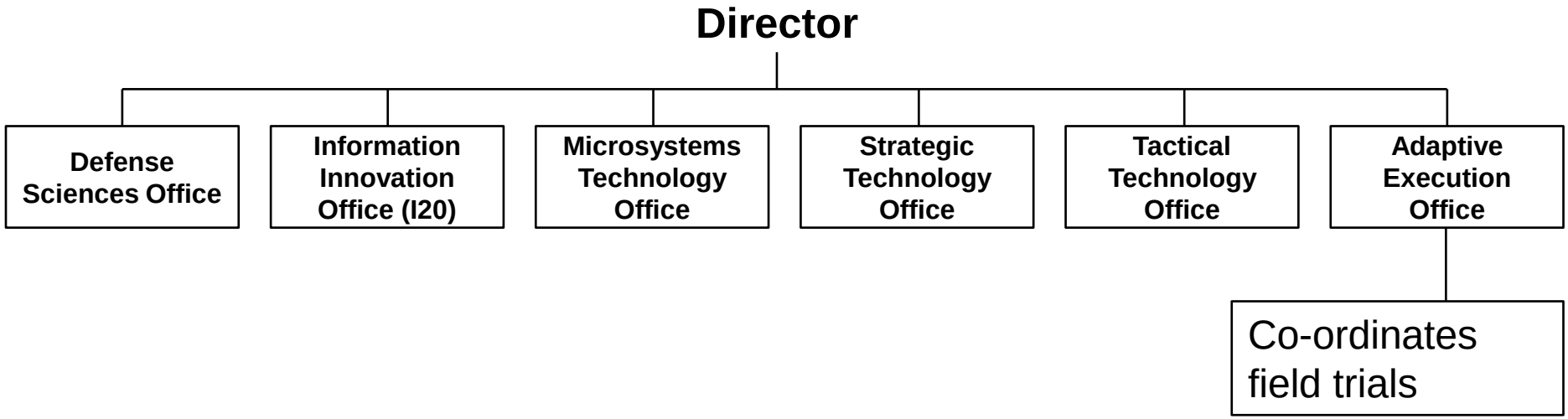


Conceptualising, demonstrating and transitioning survivable, cost effective military systems.

High-risk, high payoff development of rapid, mobile and responsive combat capability for advanced weapons platforms and space systems. Aim for order of magnitude improvements, facilitation of game changing tactics and procedures and/or addressing critical deficiencies.

- Irregular operations in difficult political/military circumstances
- Asymmetric threats
- Enabling seamless joint operations
- Situational awareness
- Global surveillance

DARPA Structure



Profile: Leo Christodoulou (DARPA 1999 to 2010)

- BSc and PhD in Metallurgy from Imperial College
- Post doc at Carnegie Mellon
- Martin Marietta Laboratories 1981-1995
- Reader, Imperial College 1995-1999
- Joined DARPA as Programme Manager in Structural Materials in 1999, later Director of Defense Sciences Office
- 60 papers, 20 patents; numerous awards
- Annual budget $700M

Profile: Leo Christodoulou (Continued)

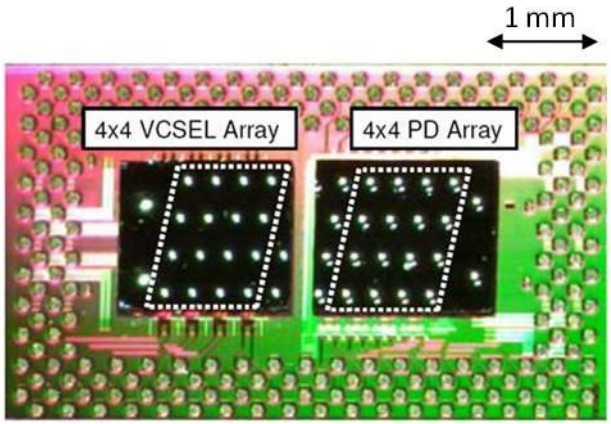
- DARPA projects include:
  - Accelerated development of multi-functional materials
  - Damage tolerance materials
  - ‘Hardwire’ armour
  - ‘Wasp’ micro air vehicle

- Funding split for Defense Sciences:
  - 30% industry (inc. university subcontractors), half to SMEs
  - 25% direct to universities (atypical cf rest of DARPA ?)
  - 20% not for profits
  - 20% to other DoD and Federal Labs inc. university based

- With Boeing since October 2012

Profile: Jagdeep Shah

- BSc University of Bombay, PhD MIT
- Distinguished Member of Technical Staff, Bell Laboratories/Lucent 1967-2001
- Programme Manager in Microsystems Technology Office 2001- today (?)
- Current programmes:
  - Chip to chip optical interconnects
  - Data in optical domain network
  - Photonically optimized embedded microprocessors (POEM)
  - Quantum Entanglement Science and Technology (QUEST)



Jagdeep Shah : EPIC and Related DARPA Programmes

- HPCS, EPIC and UNIC; are linked projects aimed at high productivity at using photonics to facilitate introchip and interchip connections
- Participants include HP, IBM, Sun Microsystems, Luxtera, BAe Systems, MIT
- EPIC objectives for early stage in process:
  i. High performance photonic devices in silicon that are foundry compatible
  ii. Produce a demonstration device that will 'do something'
  iii. Technologies for filling missing silicon capabilities
- Five year programme (2+2+1)
- Two main competing teams for tasks (i) and (ii) together – one large company, one start-up with university subcontractors
- Phase 3 UNIC Programme September 2008
  - $44M to Sun as prime contractor over 5½ years
  - of which $14M subcontracted to Kotura (Californian start-up 2004)
  - $ significant subcontract to Luxtera (Californian start-up 2001)

Profile: Professor Leslie Kolodziejski

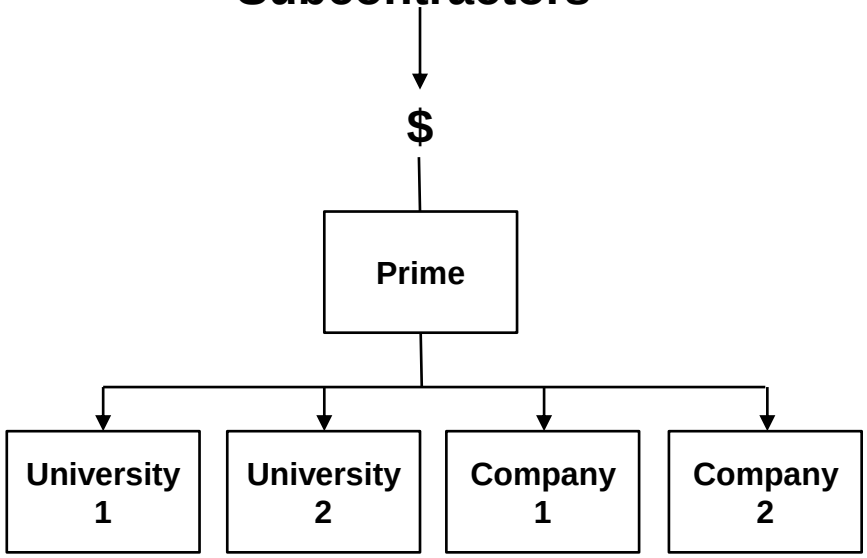
- DARPA process (under Tony Tether)
  - Invitation only meeting in Washington for interested parties
  - DARPA Programme Manager submits programme proposal for approval by Tony Tether ($20M)
  - DARPA, BAA, open to anyone indicating preferred types of participant (university, companies, collaborations)
  - 2 year contract with 9 month go/no go
  - Possible further 2 years after review
  - 6 monthly physical deliverables
- Comparison with deliverables from other funders
  - Army and Navy – physical deliverables but vague
  - NSF – ‘good science’ with education and diversity components

Typical DARPA Process

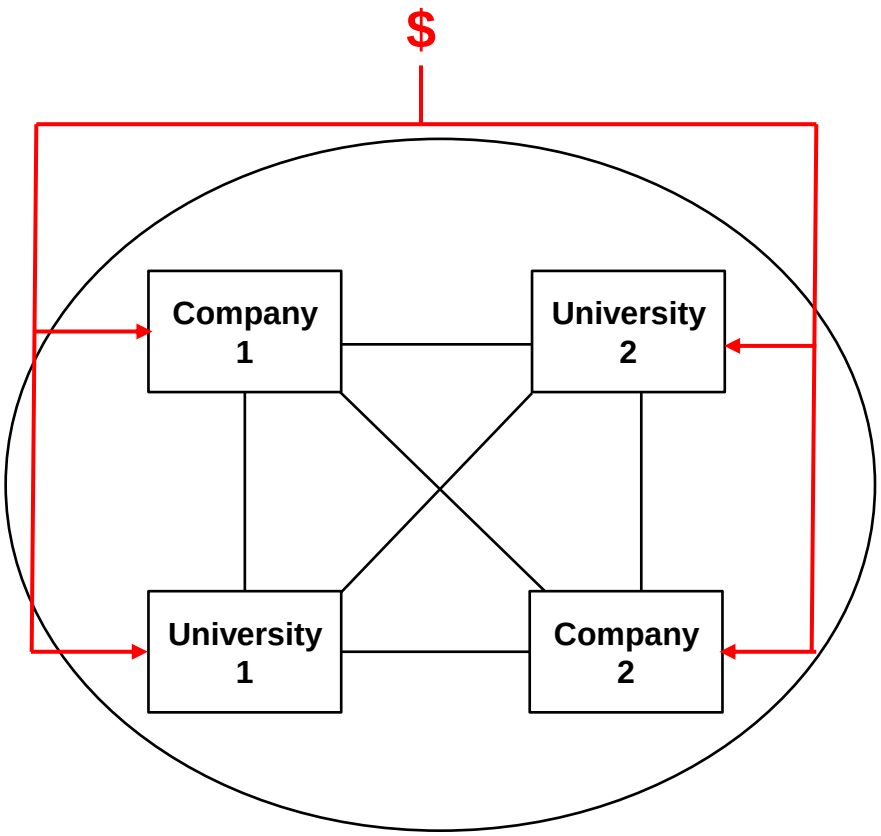
- Open door policy – informal discussions, white paper submissions
- Programme manager investigates fields of interest through conferences, discussions with people in the field and customers etc.
- Programme proposal and budget presented to DARPA Director for approval
- Meeting with invited group of possible participants
- Broad Area Announcement (BAA) inviting competitive proposals
- Phased projects with competiting teams in early phases common
- Sole sourcing where proprietary ideas

DARPA Funding Mechanisms

Preferred Funding of Partnerships is through Prime and Subcontractors



Occasionally Fund as Loose Collaboration

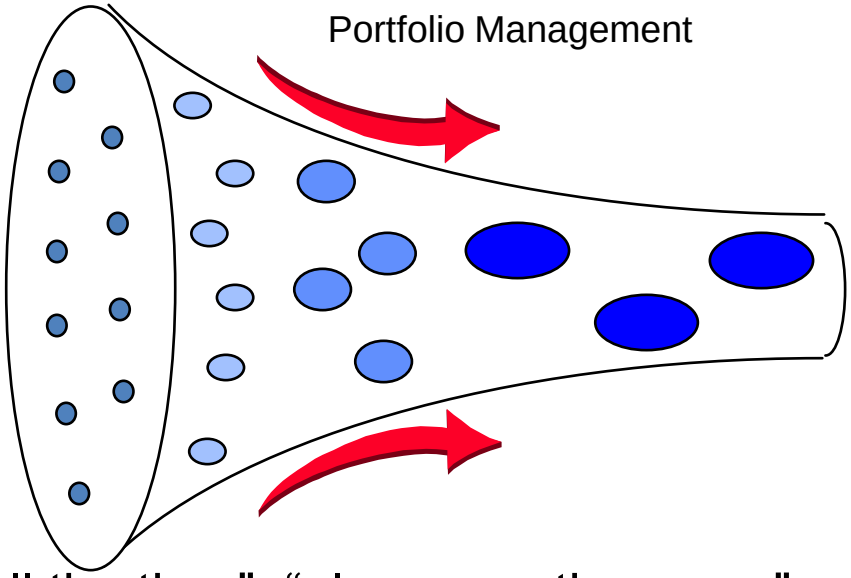


Key Features of DARPA Approach 1

- Hire excellence…rapidly
  - give them a hunting licence and the opportunity of a significant budget
  - 3 plus 2 year contracts; *"come to DARPA to serve, not for careers"*
  - 25% turnover per annum
  - Typically mid-career from academia, industry or a mix
  - Acknowledged experts in their fields
  - Ex pats OK
- Director is very powerful and stamps personal style on organisation (particularly Tony Tether 2001-2009)

Key Features of DARPA Approach 2

- Focus on delivery
  - *"there is no way to learn to fly at Mach 20 unless you build and fly"*
  - Discourage fear of failure
  - Staged approach to projects with clearly defined deliverables targets and go/no go decisions at milestones



- Active project managers; "with you all the time", "always on the move"
- May bring in new participants to solve problems or terminate projects at any time
- Weekly conference calls with 6 monthly reviews

Key Features of DARPA Approach 3

- Programme managers have to secure budgets from DARPA Director but then seem to have substantial discretion –
- No peer review process; more like a VC process than a government contract
- No aversion to start-ups
- Can fund anywhere in the world (but participation by non-US organisations seems mainly to be via prime contractors)

Key Features of DARPA Approach 4

- Funding mechanisms:
  - Standard government contracts
  - Grants (for university academics)
  - “Other transactions” – e.g. milestone based, prototype purchase
  - Some Grand Challenge Competitions
- Contracts worth $10s million, especially for later phases
- 100% funding
- Series of related projects with key primes create sustained competence in depth

Lead Customer Pull and Exploitation

- *Customer* not *grant provider*
- DARPA a “marriage broker” between potential DoD customers with a need and potential suppliers and experts with disruptive technology
- IP resides with contractor; aim is to encourage translation into use for benefit of US
- Handover to other operational Dod agencies for completion and deployment the norm
- Final product delivery may be steered through a prime

COMMENT; technology developed against very difficult mission objective may find application first in a much easier one, e.g.:

- SRI’s robotic surgery technology funded by DARPA
- CCL’s ink jet technology funded by ICI

UK DARPA Projects – "Blood Pharming" for Battlefield Uses

- Lead contractor – Celgene ($5b revs; 4000 employees)
- TAP BioSystems (£18m revs; 160 employees)
- Plus University of Pittsburgh, Ohio State University, Fred Hutchinson Cancer Research Centre, Loughborough University, Fraunhofer Centre for Molecular Biology, Delaware
- Phase 1 (Aug 2008 to July 2009) – two consortia with approx $1-3m each; $150k to TAP BioSystems
- Phase 2 (Aug 2009 to June 2012) – one consortia led by Celgene; $10-15m with $1-3m to TAP BioSystems
- Did not proceed to Phase 3 as too difficult; new DARPA project to exploit Celgene technology in another application

UK DARPA Projects – "Blood Pharming" for Battlefield Uses

Project management:

- Very close relationship between prime and DARPA, with 1-2 hour weekly conference calls
- Subcontractors paid by Celgene
- Extremely impressive DARPA Project Manager (Army Colonel and Doctor); contractor used for day to day stuff

"Unlike TSB, DARPA is a customer; they want the output"

"If its possible DARPA don't do it!"

UK DARPA University Projects

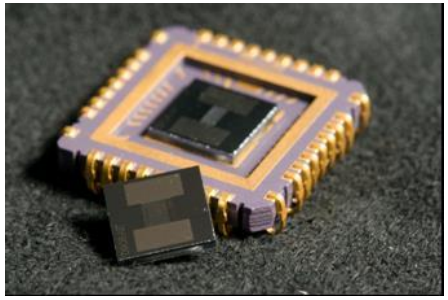
- University of Cambridge Machine Intelligence Lab Speech Research Group:
  - ‘AGILE’ Autonomous Global Integrated Language Exploitation

- Imperial College
  - ‘GOAD’ – gene-based optic activity detector system

Other UK DoD Contracts

- Akubio Ltd, Cambridge - Resonant acoustic profiling for detection of molecular interactions

- Owlstone Ltd, Cambridge - $5M from US Threat Reduction Agency for FAIM electronic nose technology development



Commercialisation of Cambridge FFC (FRAY) Process

Cambridge University
FFC process for production of titanium and other metals by salt electrolysis (1997)

Professor Derek Fray

Licence for Ti

Licence for other metals

METALYSIS (2001)

BHP BILLITON

BRITISH TITANIUM (1998)

Sub licence

DERA

QinetiQ

DARPA (2003)

Sub licence

$12.5M

TIMET

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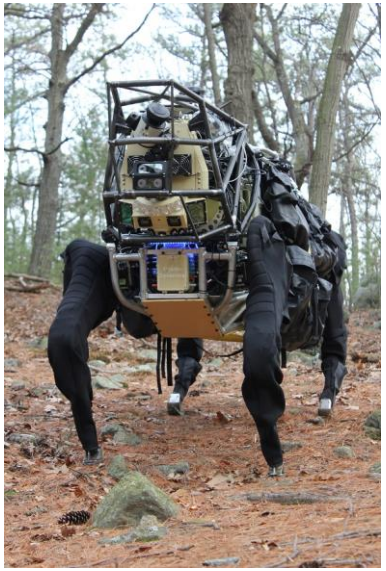


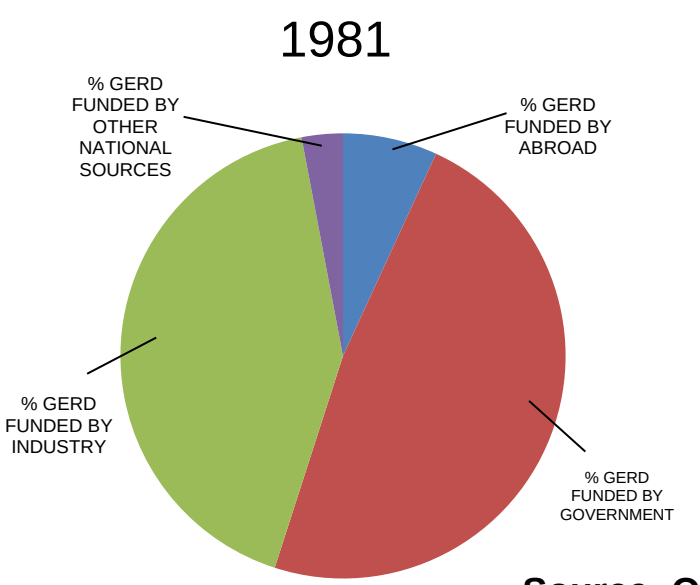
How the US Federal Government uses R&D Budgets to Stimulate the Technology Sector

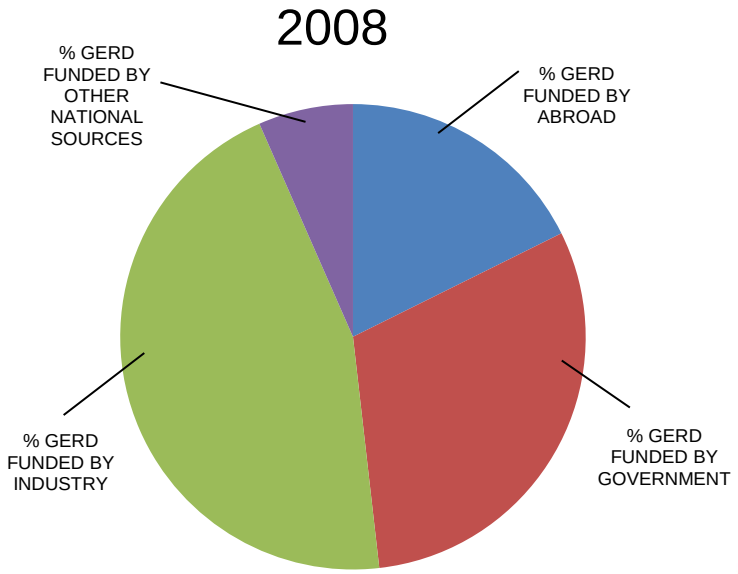
- Key role of US Federal Government in national R&D system recognised since the start of the Cold War – pivotal in development of semiconductor, computer and other sectors
- Federal Government R&D expenditure approximately $147 billion in 2009, 40% with industrial companies
- DARPA R&D represents approx 2% of this total
- Total Department of Defense R&D is around 30 times DARPA budget
- Key role of small US companies in innovation and job creation
  - 13-14 times as many patents per employees as large companies
  - 60-80% of new jobs over the last decade

Some Key Features of US Innovation System 1

- Very high level of industry funded R&D (1.8% c.f. 0.8%)
- Very high percentage of business R&D financed by Government (14% c.f. 8%)
- Very high level of Federal Government funded R&D (0.9% GDP c.f. 0.6% in UK, equivalent to a £4.5 billion gap)

Changes in the Balance of UK Gross Domestic Expenditure on R&D in the UK





Source: OECD R&D Statistics

Some Key Features of US Innovation System 2

- Extensive network of Federal Government Laboratories – GOCOs and FFRDC, including:
  - Lawrence Berkeley
  - Los Alamos
  - Sandia
  - Lawrence Livermore
  - Argonne
  - Oak Ridge
  - Jet Propulsion Laboratory
- 720 labs in all, employing approx 100,000 people
- Increasingly interested in industry collaboration and spin-outs

Some Key Features of US Innovation System 3

- Independent, not-for-profit research organisations, including:
  - SRI International
  - Battelle Memorial Institute
  - Research Triangle Institute
  - Midwest Research Institute
  - Southern research Institute
  - Southwest Research Institute
- These six have 10,000 employees collectively and are approx. 70% Federal Government funded
- Many specialist R&D contractors (e.g. SAIC, Foster Miller)
- Many large private sector organisations able to act as lead customers

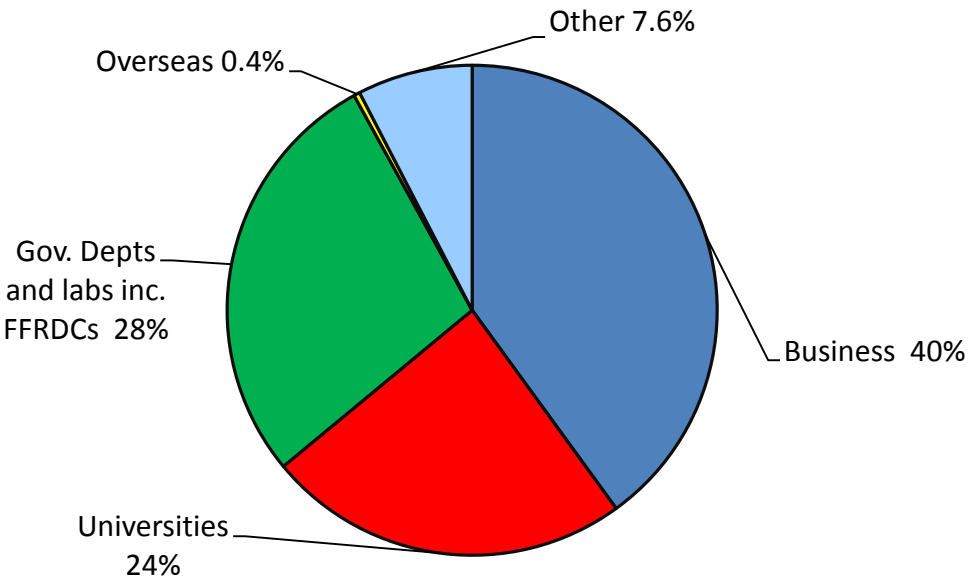
Some Key Features of US Innovation System 4

- DoD has 15 University Affiliated Research Centres, described as like FFRDC's and ranging from the Soldier Nanotechnologies Centre at MIT to the John Hopkins University Applied Physics Laboratory (APL)

  APL employs 4,500 people and is described as primarily a defence contractor rather than an academic division of the university

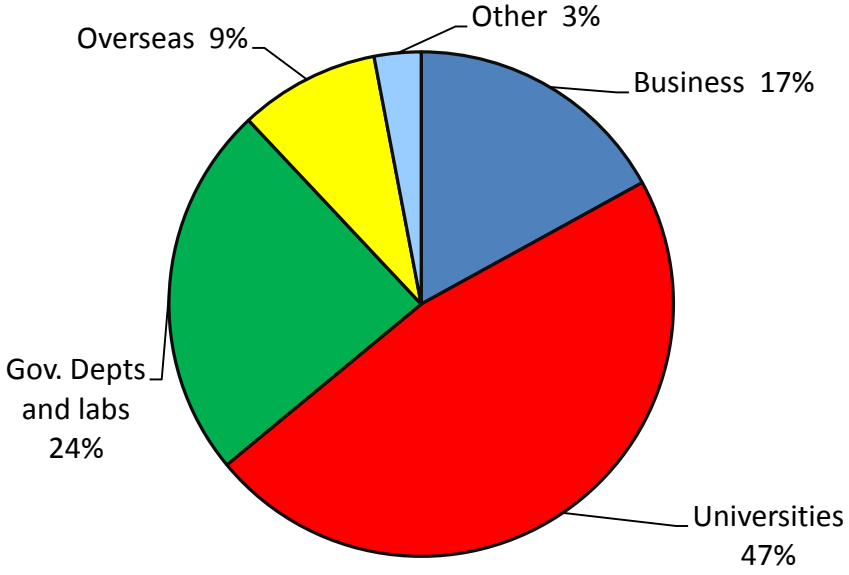
Government R&D Expenditure by Performing Sector

US
(Federal Gov. exp. 2009, NSF Data)



Total Direct	$147.0b
R&D Tax Credits	$8.3b

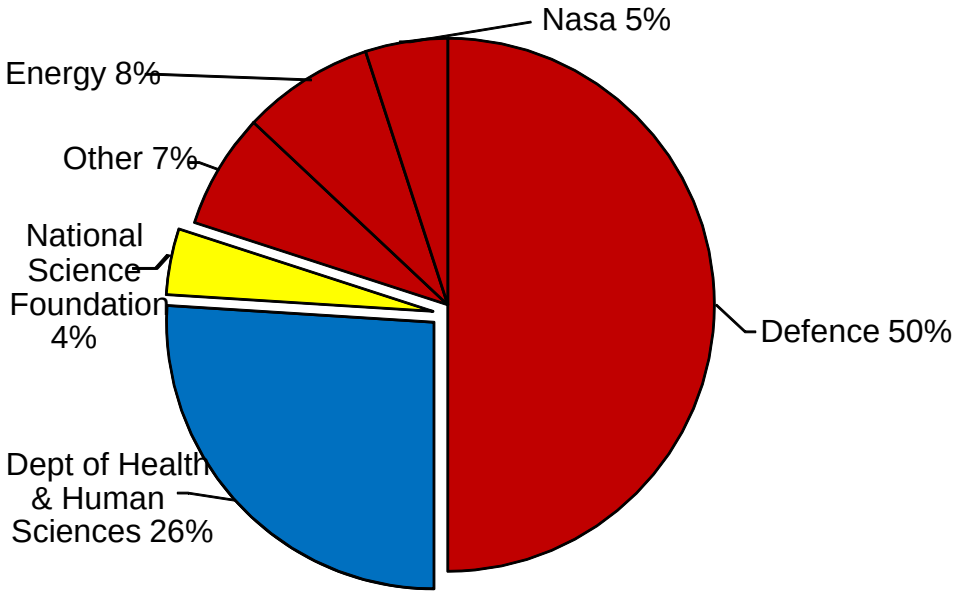
UK
(UK Gov. 2009/10 BIS SET)



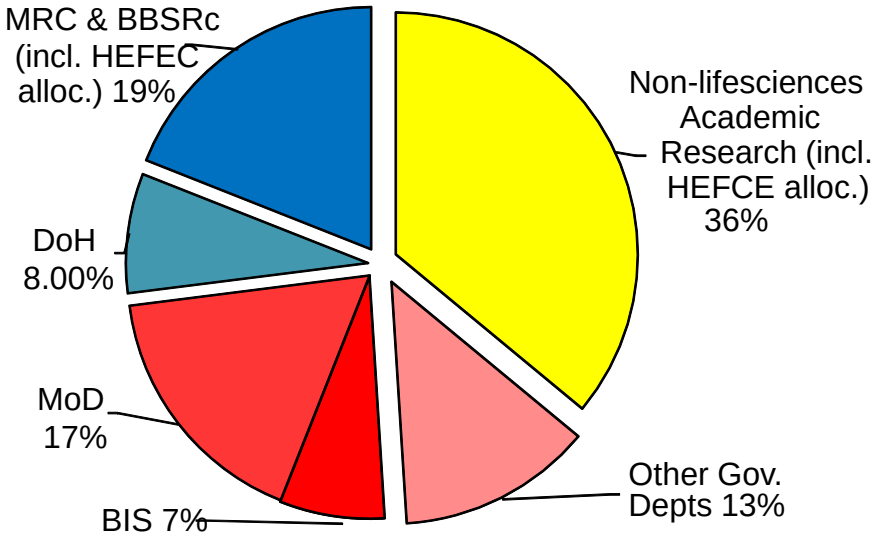
Total Direct	£9.7b
R&D Tax Credits	£1.0b

Government R&D Expenditure by Source

US Federal R&D Funding 2008



UK Government R&D Expenditure 2010



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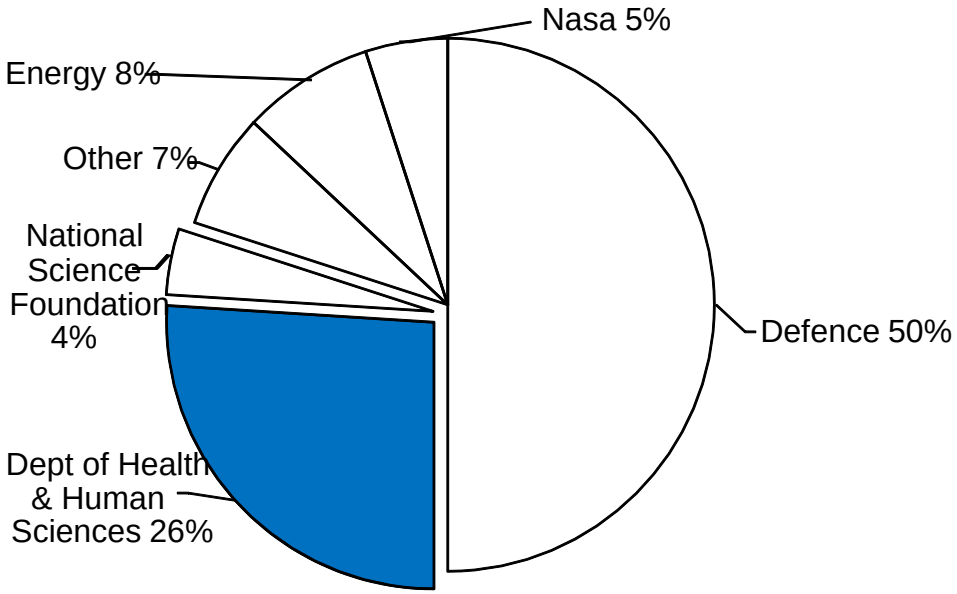

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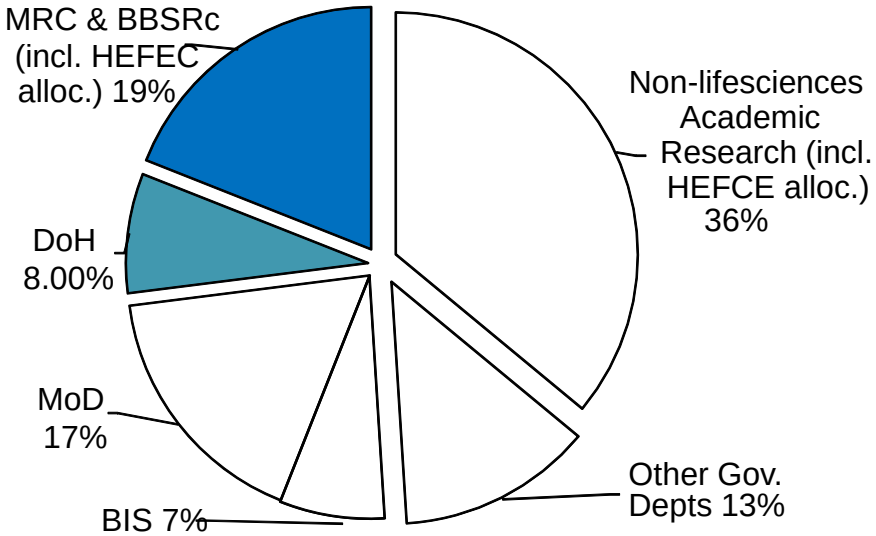

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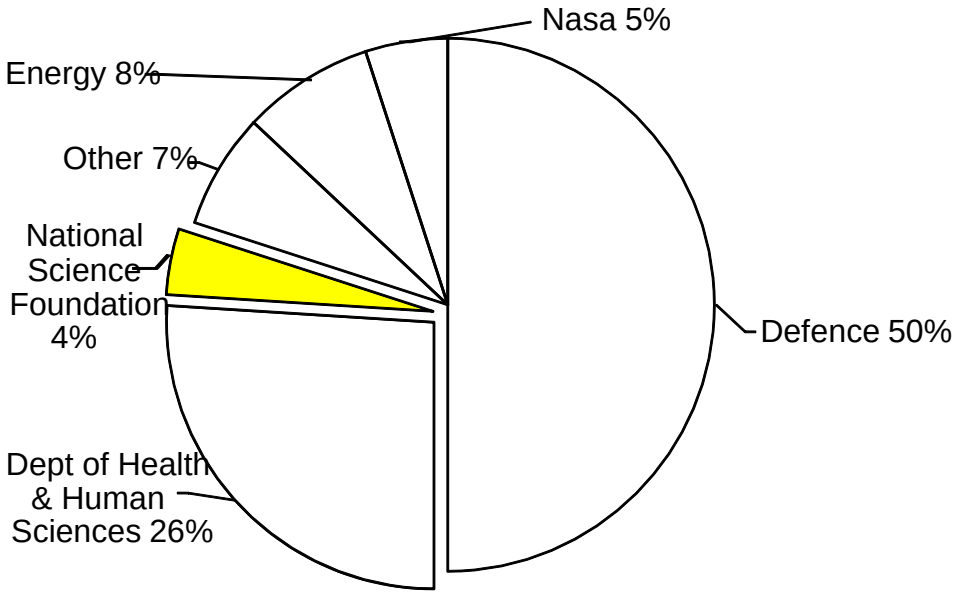
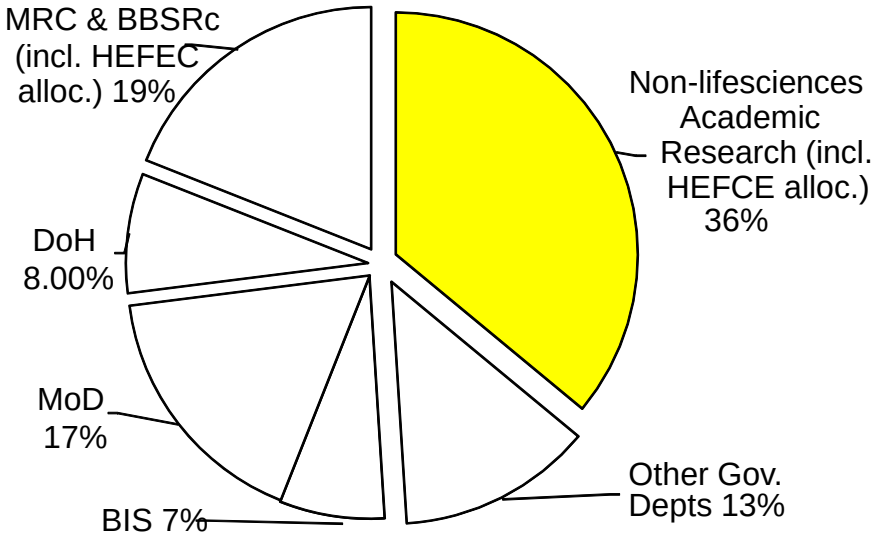
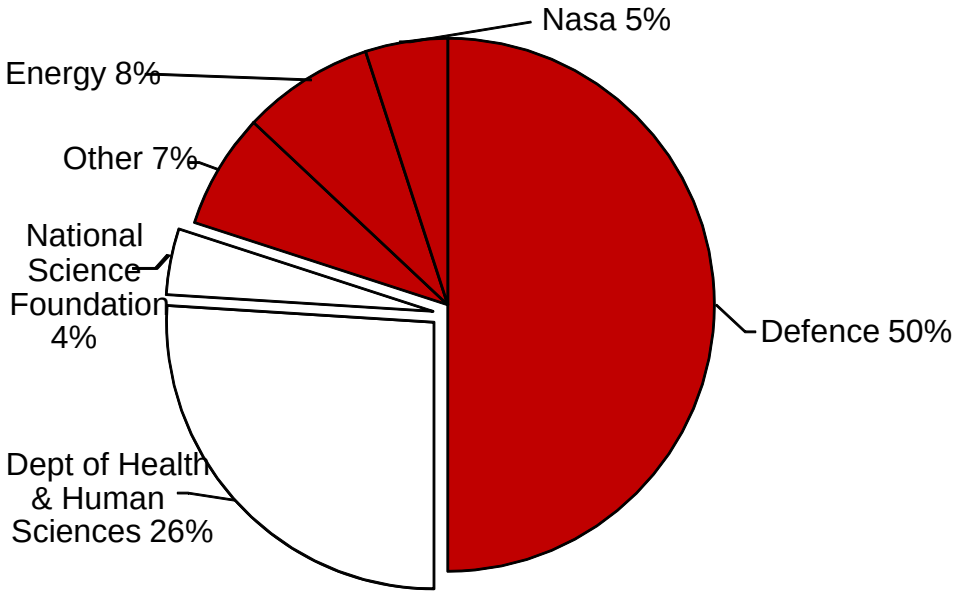


UK Government R&D Expenditure 2010



Government R&D Expenditure by Source

US Federal R&D Funding 2008



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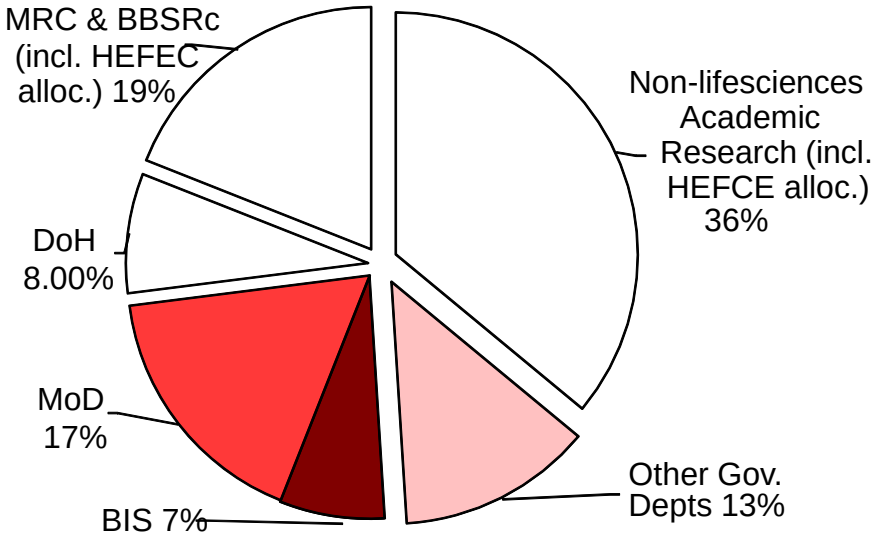


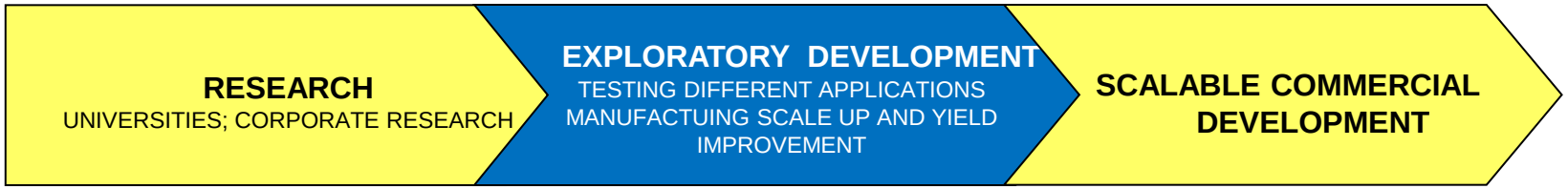
Some Key Features of US Innovation System 4

- DoD has 15 University Affiliated Research Centres, described as like FFRDC's and ranging from the Soldier Nanotechnologies Centre at MIT to the John Hopkins University Applied Physics Laboratory (APL)

  APL employs 4,500 people and is described as primarily a defence contractor rather than an academic division of the university

- Research in physical sciences and engineering in most US universities is predominantly funded by delivery orientated Federal Agencies

Turning Research into Products



SIGNIFICANT DOD AND OTHER FEDERAL FUNDING INTO EXPLORATORY DEVELOPMENT

SRI Speech Technology Spin-offs

- Independent not-for-profit R&D institute since 1970; acquired RCA Sarnoff Lab in 1987
- 2100 staff, $495m revenues:
  - 59% from DoD
  - 32% from other federal agencies
  - 6% from US businesses
- Speech technology funded by DARPA since 1971
  - Nuance spun out with 4 employees in 1994 following 1984 “Strategic Computing Programme”
  - Later reversed into competitor, now 6000 employees; $1.4 billion revenues
  - SIRI spun out 2007 following DARPA’s “ Cognitive Assistant that Learns and Organises” ($22m over 2003-2008)

    Sold to Apple for $150-250m in 2020
- In 2011 SRI won two DARPA speech technology contracts totalling $20m
- Speech Technology and Research(STAR) lab has some 25 people

SRI Automated Surgery Spin-off

- Early work at NASA Ames Lab in late 1980s
- Ideas bought to Phil Green, SRI “inventor”
- NIH funding from 1992 to 1995
- ARPA funded project for remote battlefield surgery 1993-1999; trial operations on pigs; feedback from 30 practising surgeons
- Intuitive Surgical established with $5m of VC in November 1995: focus on key-hole surgery requiring fine control
  - First operations by “da Vinci” in 1997
  - 2400 people; $2.2 billion revenues

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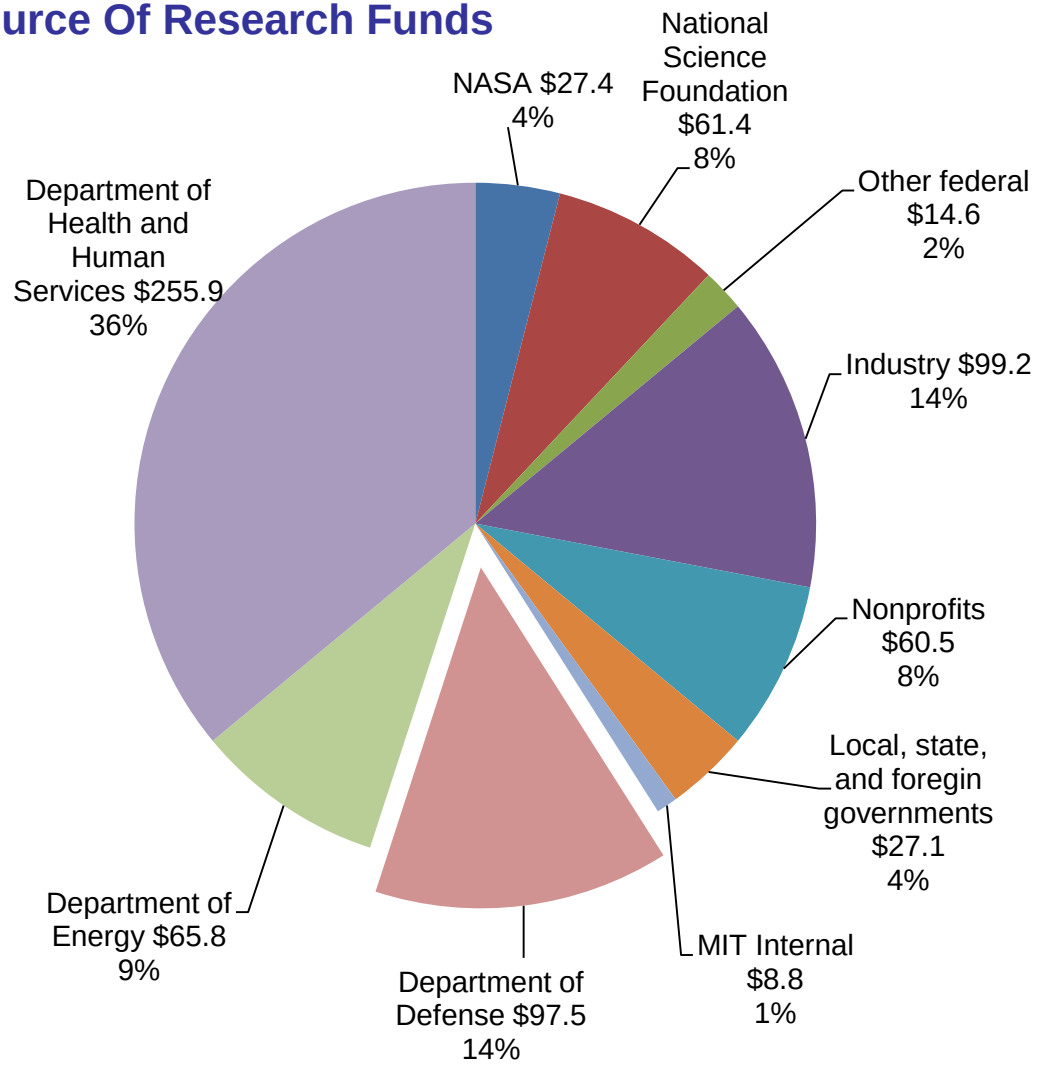
  - 2400 people; $2.2 billion revenues
- Continuing SRI work on original battlefield concept:
  - 1998 DARPA contract; machine tested by NASA in 2007
  - 2005 DARPA contract for “Trauma Pod” containerised system

MIT Research and Relationship with DoD

- Very interdisciplinary
- Diverse funding sources
- Separation of academic excellence and business activities:
- 9 month contracts; private consulting one day per week
- Corporate sponsorship tends to be through umbrella programmes

  "No-one is owned by anyone"
- No imbedded corporate labs

Source Of Research Funds



MIT and Defence R&D

- Lincoln Laboratory – 2800 staff
  - Managed by MIT as FFRDC
  - Origins in MIT “Radiation Lab work on WW2 radar
  - Established to develop cold war air defence (SAGE)
  - Spin outs include DEC (peak employment 140,000)

MIT and Defence R&D

- Lincoln Laboratory – 2800 staff
- Mitre Corporation – 7000 staff
  - Lincoln lab spin out to provide system engineering support for SAGE
  - Now manages 4 FFRDCs

MIT and Defence R&D

- Lincoln Laboratory – 2800 staff
- Mitre Corporation – 7000 staff
- Draper Laboratory - 1300 staff
  - Origins in MIT Instrument Lab
  - FFRDC with key focus on “vanishingly small systems”
- MIT Institute for Soldier Nanotechnologies

MIT “Spin-out” iRobot

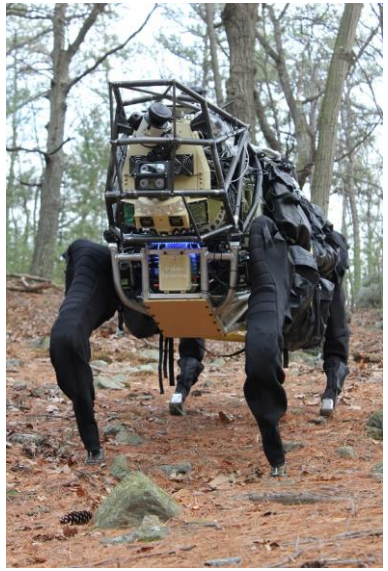
- Founded in 1990 by Colin Angle (CEO), Helen Greiner and Prof Robert Brooks
- Soft start: DoD contracts from 1993
- DARPA funded “Packbot” provided breakthrough
- $34m of VC from 1998 until IPO in 2005
- First floor cleaning robot sold in 2002 (consumer products up to 75% of revenues since then)
- 64% of R&D funded by government contracts
- *“...we use technological expertise developed through government funded R&D across our other product development efforts...”*

STRUCTURE OF PRESENTATION

1. DARPA

1. RELATIONSHIP TO BROADER US INNOVATION SYSTEM

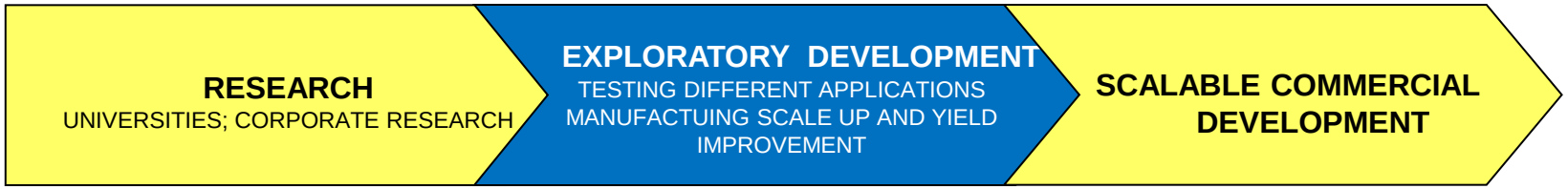
1. WOULD A UK DARPA ADDRESS THE POLICY CHALLENGE ?



Weaknesses in UK Government R&D Spending

- Overall level of reported annual Government R&D spending is around £4.5 billion below direct competitors given relative size of economy
- UK Government spending heavily skewed to funding university research
- Policies implicitly overestimate both value of university research and ease with which it may be commercially exploited within the UK
- Reported expenditure on R&D by departments is overstated and the proportion on technology development (as opposed to academic research and policy development) is very small *(Source. Unpublished research by David Connell)*
- Policies to fund R&D in businesses (grants, R&D tax credits) cover only a proportion of costs so ill suited to exploratory development in general and SMEs in particular. Emphasis on R&D tax credits at variance with US and most other direct competitors
- Most funding is NOT through lead customers (except SBRI)

Turning Research into Products



UK POLICY GAP

BUDGETS AND MECHANISMS FOR LONGER TERM MISSION DRIVEN DEVELOPMENT

PUTTING DARPA IN CONTEXT

- DARPA philosophy is an extreme version of the DoD and wider US Federal Government approach to funding R&D; this approach underpins innovation policy in the US
- Focusing on DARPA alone risks understating the level of Federal funding for similar projects, especially in businesses and intermediate research labs focused on exploratory development
- For SMEs this is most visible through SBIR, worth $2.5 billion per annum, but there is much more, and in larger amounts, available for SMEs through weakly documented SBIR Phase 3 funding and other unrelated contracts and grants
- Scale permitted by size of US economy

KEY LESSONS FROM DARPA

1. **100% funded projects and sufficient funding per project to make a real impact per project**

   Because of EU State Aid Rules the equivalent can only be achieved through procurement contracts. These are now actively encouraged by the EU Commission as “Pre-Commercial Procurement Contracts”

2. **An informed, demanding customer**; compared with the traditional UK grant mechanism, this confers huge benefits on both the process and the quality of deliverables; it is relevant to both difficult, far from market projects like DARPAs and near to market projects

3. **Competitive, phased projects** with clear milestones enabling technical progress to be tested; this impacts supplier behaviour and focuses funding on the best projects and solutions

KEY LESSONS FROM DARPA

4. A **process much closer to the VC model** - less governance for a publicly funded body than the UK norm?

5. **Programme Managers that are experts in their fields and act more like entrepreneurs** than officials; this requires freedom and the ability of individuals to develop skills that enhance their CVs

6. Level of research and planning that goes into defining programmes and projects

7. Fixed term contracts, not careers

8. Administrative economies of scale

9. Outsourcing of non-entrepreneurial functions; NB Unlike DARPA a UK equivalent would lack the broader MOD R&D structure on which to draw

DC's Proposals to House of Common's Science and Technology "Valley of Death" Inquiry

1. Expand SBIR to £250m per annum
   - better adherence to model, with VC like features as practised in NHS (East) SBRI competitions
   - planning and road maps to ensure coverage of full range of technologies and a balance of near to, and far from, market propositions
   - open door to seed competition ideas
2. Additional £250m for Phase 3s and ad hoc larger projects, still on 100% funded contract basis (implicit cost sharing always possible for larger companies)
3. £100m per annum, private sector lead customer programme, based on SBIR philosophy, to widen range of technologies and propositions (DC has supplied proposals for funding within EU rules)

Further Information: www.davidconnell.org