The Italian Research Center in High Performance Computing, Big Data and Quantum Computing

Spoke 10: Quantum Computing

High Performance Computing and Quantum Computing – Fifth Edition
15 December 2022, CINECA; Bologna
Innovation in simulations, high-performance computing and big data

SoA infrastructure: integrating existing resources and promoting new technologies

Supporting scientific research and entrepreneurial innovation

One of the five National Centres established by the PNRR
The Italian Research Center in High Performance Computing, Big Data and Quantum Computing

- Headquarters at the Bologna Technopole
- Activities started on 1 September 2022
- Official kick-off at Bologna Technopole on 25-26 November 2022
- Created and managed by the ICSC Foundation

319,938,979,26 €
Organization in "thematic" Hubs and Spokes

Organized according to the HUB and SPOKE model

**HUB**: carries out management and coordination activities

**SPOKE**: carry out research and innovation activities
The Spokes

spoke 0
SUPERCOMPUTING
CLOUD INFRASTRUCTURE

spoke 1
FUTURE HPC & BIG DATA

spoke 2
FUNDAMENTAL RESEARCH & SPACE ECONOMY

spoke 3
ASTROPHYSICS & COSMOS OBSERVATIONS

spoke 4
EARTH & CLIMATE

spoke 5
ENVIRONMENT & NATURAL DISASTERS

spoke 6
MULTISCALE MODELLING & ENGINEERING APPLICATIONS

spoke 7
MATERIALS & MOLECULAR SCIENCES

spoke 8
IN-SILICO MEDICINE & OMICS DATA

spoke 9
DIGITAL SOCIETY & SMART CITIES

spoke 10
QUANTUM COMPUTING
Spoke 10: Quantum Computing

Budget: 30 mil. di €
<table>
<thead>
<tr>
<th>15 research institutions</th>
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</thead>
<tbody>
<tr>
<td>Politecnico di Milano</td>
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<tr>
<td>Università di Padova</td>
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<tr>
<td>CINECA</td>
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<tr>
<td>Consiglio Nazionale delle Ricerche (CNR)</td>
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<tr>
<td>Istituto Italiano di Tecnologia (IIT)</td>
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<tr>
<td>Istituto Nazionale di Astrofisica (INAF)</td>
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<tr>
<td>Istituto Nazionale di Fisica Nucleare (INFN)</td>
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<tr>
<td>Università di Bari</td>
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<tr>
<td>Università di Bologna</td>
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<tr>
<td>Università di Catania</td>
</tr>
<tr>
<td>Università di Milano-Bicocca</td>
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<tr>
<td>Università di Napoli</td>
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<tr>
<td>Università di Pavia</td>
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<tr>
<td>Università di Pisa</td>
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<tr>
<td>Università di Roma-Sapienza</td>
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</table>
14 founding companies

- Autostrade
- Engineering
- Enel
- Eni
- Ferrovie dello Stato Italiane
- Fincantieri
- Fondazione per l’Innovazione Urbana
- Humanitas
- IFAB
- Intesa Sanpaolo
- Leonardo
- SOGEI
- Thales Alenia Space
- Terna
- Unipol Sai
### Many other interested companies

<table>
<thead>
<tr>
<th>CNH Industrial</th>
<th>Esteco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kmrosso</td>
<td>Bonfiglioli</td>
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<tr>
<td>Atos</td>
<td>Confindustria Emilia</td>
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<tr>
<td>Bip</td>
<td>Agile Labs</td>
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<tr>
<td>Prometeia</td>
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<tr>
<td>Quantyca</td>
<td></td>
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<tr>
<td>Seco</td>
<td></td>
</tr>
<tr>
<td>E4 Computer Engineering</td>
<td></td>
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Objectives

Research and development of quantum computers “scalable” and “reliable”

Using quantum computing for the solution of complex problems
The research landscape

**Software**

- **Applications and Algorithms**
  - Development of libraries to use quantum computers as accelerators
  - Development of high-level quantum algorithms to solve ad-hoc scientific and industrial problems, and general-purpose problems

- **Compilation Emulation Benchmarking**
  - Development of software for compilation, benchmarking, verification, emulation of quantum computers and algorithms

- **Firmware and Hardware platforms**
  - Development of low-level software for the physical operation of quantum computers
  - Development of the quantum computer hardware chain in its four most promising forms: ions, atoms, photons and superconductors

**Hardware**
Organization in Layers and Workpackages

WP1. Software
  Layer 1. Applications
  Layer 2. Algorithms

WP2. Middleware
  Layer 3. Emulation
  Layer 4. Compilation

WP3. Hardware
  Layer 5. Firmware
  Layer 6. Hardware
Organization in Layers and Workpackages

**WP1. Software**
- Layer 1. Applications
- Layer 2. Algorithms

**WP2. Middleware**
- Layer 3. Emulation
- Layer 4. Compilation

**WP3. Hardware**
- Layer 5. Firmware
- Layer 6. Hardware

**Leader: INFN**

Development of quantum software for algorithms applications (scientific and industrial)
- T1.1 New algorithms
- T1.2 Applications and use cases
Organization in Layers and Workpackages

**WP1. Software**
- Layer 1. Applications
- Layer 2. Algorithms

**WP2. Middleware**
- Layer 3. Emulation
- Layer 4. Compilation

**WP3. Hardware**
- Layer 5. Firmware
- Layer 6. Hardware

**Leader: CINECA**
Software development for compilation, benchmarking, validation, and emulation
- T2.1 Compilation
- T2.2 Emulation
Organization in Layers and Workpackages

**WP1. Software**
- Layer 1. Applications
- Layer 2. Algorithms

**WP2. Middleware**
- Layer 3. Emulation
- Layer 4. Compilation

**WP3. Hardware**
- Layer 5. Firmware
- Layer 6. Hardware

*Leaders: CNR, Catania*
Development of low-level software for the physical operation of quantum computers. Hardware development and support.

- T3.1 Photonic hardware
- T3.2 Superconducting circuits
- T3.3 Atomic hardware
- T3.4 Models and firmware
The global landscape on Quantum Computing
Private investments

Europe
- USD: 338 mln
- # players: 64

Canada
- USD: 321 mln
- # players: 21

USA
- USD: 1.062 mln
- # players: 38

Asia
- USD: 19 mln
- # players: 13

Australia
- USD: 47 mln
- # players: 4
Public investments

**Europe**
- **USD**: 8,9 mld
- **period**: 2014-2029
- **€/anno**: 517 mln

**Asia**
- **USD**: 12,4 mld
- **period**: 2014-2030
- **€/anno**: 613 mln

**USA**
- **USD**: 1,2 mld
- **period**: 2018-2022
- **€/anno**: 250 mln

**Canada**
- **USD**: 0,79 mld
- **period**: 2010-2019
- **€/anno**: 74 mln

**Australia**
- **USD**: 0,09 mld
- **period**: 2016-2025
- **€/anno**: 9 mln

**Russia**
- **USD**: 0,79 mld
- **period**: 2020-2024
- **€/anno**: 165 mln
## Industrial problems and areas

<table>
<thead>
<tr>
<th>Industry / Segment</th>
<th>Description</th>
<th>Optimization</th>
<th>Simulation</th>
<th>Pattern Rec. / Class.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry / Pharma</td>
<td>Drug discovery, disease pattern discovery, material design</td>
<td>1</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Finance</td>
<td>Portfolio opt, price determination, risk mng, credit scoring, currency arbitrage</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Aerospace / Defence</td>
<td>Aircraft design, climb opt, route opt, gate assignment, aircraft surveilling</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Energy / Utility / Telco</td>
<td>Energy efficiency, network design, drill path opt, battery design, maintenance</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Components / material design, asset sustainment, logistics / SCM</td>
<td>2</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Automotive</td>
<td>Traffic opt, supply chain opt, operations opt, battery design</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Logistics / Retail</td>
<td>Route opt, supply chain opt, network opt, traffic allocation</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>Weather forecasting, marketing content distribution</td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

### Percentage

- Chemistry / Pharma: 24%
- Finance: 19%
- Aerospace / Defence: 15%
- Energy / Utility / Telco: 12%
- Manufacturing: 11%
- Automotive: 9%
- Logistics / Retail: 6%
- Services: 4%

CINECA (Bologna), 15.12.2022
Paolo Cremonesi
Patents on Quantum Computing

Number of patent applications (cumulated)

Number of patent applications (annual increase)

- 2017: 98 (cumulated), +55
- 2018: 254 (cumulated), +156
- 2019: 702 (cumulated), +448
- 2020: 1,581 (cumulated), +879
- 2021: 2,734 (cumulated), +1,153
- 2022: 2,978 (cumulated), +244

+2,935 Patent applications on Quantum Computing in the last 5 years

CINECA (Bologna), 15.12.2022
Paolo Cremonesi
Patents on Quantum Computing

Breakdown of the main 10 applicants: 1,100 patents

- IBM: 33%
- Baidu: 7%
- Google: 12%
- Rigetti: 11%
- Microsoft: 10%
- IonQ: 8%
- Origin Quantum: 8%
- University of Science and Technology of China: 7%
- D-wave: 4%
- Intel: 3%

72% from USA companies
20% from Chinese companies
Academic research

56,161 papers since 1990

+22,170 Papers on Quantum Computing in the last 5 years

Publication rate increases after 2015
Top 10 countries (# of papers)

- **US**: 14,919 papers (27%)
- **China**: 12,133 papers (22%)
- **Germany**: 5,138 papers (9%)
- **UK**: 4,597 papers (8%)
- **Japan**: 3,719 papers (7%)
- **Canada**: 3,081 papers (5%)
- **Italy**: 2,714 papers (5%)
- **India**: 2,602 papers (5%)
- **France**: 2,328 papers (4%)
- **Australia**: 2,289 papers (4%)

Range: 0 - 15,000 papers
Thanks