Patents and patent statistics: an insight into the secrets of technological development?

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Outline

- Technological trajectories: a focal issue in evolutionary economics
- Mapping technological trajectories as patent citation networks (fuel cells)

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References

- Dosi, G. (1982), "Technological paradigms and technological trajectories", *Research Policy*, 11, pp. 147-162.
- Hummon, N.P. and Doreain, P, 1989, 'Connectivity in a Citation Network: the Development of DNA Theory', *Social Networks* ,11 (1989) 39-63.
- Saviotti, P. P. and Metcalfe, J. S. (1984), "A theoretical approach to the construction of technological output indicators", *Research Policy*, 13, pp. 141-151.

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The economic reason for patents

- Incentive problem
- Patents and welfare loss (monopolies)
- Patents and spillovers

- Strategic patenting (costs of litigation)

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Patent statistics

- Patent counts
  - Measuring technological competitiveness or technological specialization
- Patent citations
  - Measuring technology flows or technology spillovers

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Application: mapping technological trajectories

- Technological trajectory as a selection device: why are certain parts of technology space researched and others not?
- Technological trajectories are the ordered patterns of technological change that result from engineers working in a technological paradigm
- A paradigm is the frame of mind (cognitive framework) commonly used by engineers in the area, and can be "deconstructed" into a set of rules (e.g., in order to increase the duty of an engine, increase the rate of expansion)

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How do trajectories emerge?

- "Autonomous drift" and "compulsive sequences": the internal logic of the technology
- Induced by economic and other social factors (e.g., factor prices, demand patterns)
  - Coal and steam engines in Cornwall

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Implications of trajectories

- Technological change is local: small variations to existing directions (bounded within a selective region of technology space)
- Cumulative: depend on previous attainments
- Irreversible: once developed into one direction, the trajectory tends to dominate alternative solutions in a wide variety of circumstances
- But: trajectories do run into dead ends, and paradigm-shifts do happen

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A research niche

- Existing quantitative literature focuses on interactions between users and technology (markets)
- Mapping the "inner dynamics" of engineering trajectories is the domain of qualitative history
- This study proposes a specific way of quantifying this

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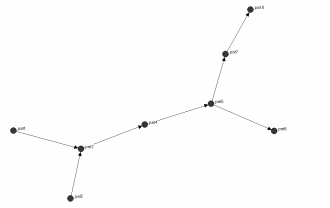
Why citation networks?

- Basic notion: citations are "paper trails" of the relatedness of ideas
- Thus, a citation path (a linked set of citations) should reflect the notion of a technological trajectory (cumulativeness, selectivity, etc.)

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Hummon and Doreian (1989)

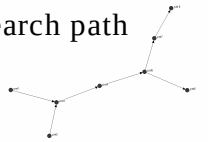
- Application to DNA theory
- Citation networks are
  - Directed
  - Acyclic



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Measuring the importance of edges

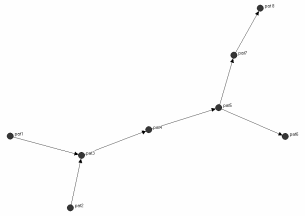
- Some edges have more knowledge flowing through them than others…
- Search Path Link Count (SPLC): enumerates all possible search paths in the network, and counts how often an edge lies on such a search path



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An alternative: SPNP

- Search Path Node Pair (SPNP): “accounts for all connected node pairs along the search paths” (weights links in the middle more heavily)



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Main path(s)

- A heuristic procedure:
  - start at a startpoint, and travel along the (outward) edge with the highest SPx …
  - Repeat at the destination …
  - Until an endpoint is reached.
- This is called a main path
- Hummon and Doreain propose to look at the single main path that has the highest first value of SPx

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The H&D main path in DNA literature

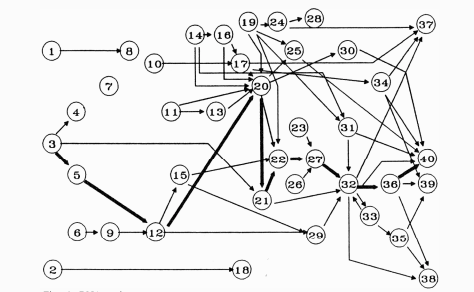


Fig. 4. DNA main stream.

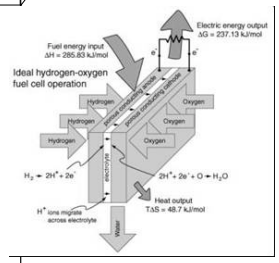
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Alternative:

- Look at all main paths emerging from all startpoints
  - Some main path will converge to other main paths
  - Some main paths will converge to the same endpoint
  - Some main paths will remain unconnected (in separate components)

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Fuel cells



Fuel cell types (classified mainly on the basis of the material for the electrolyte)

Fuel cell type	*Technical characteristics*	*Operating characteristics*
Polymer Exchange Membrane (PEMFC)	A polymer electrolyte, clothed by a catalytic material (usually platinum), electric efficiency ~ 50%	Low operating temperatures (80 C), operates only on pure hydrogen, 50 – 250 kW
Alkaline (AFC)	Alkali electrolyte, electric efficiency up to 70%	High operating temperature (200 C), operates only on pure hydrogen, 300 W – 5 kW
Phosphoric Acid (PAFC)	Electrolyte made of concentrated phosphoric acid, electric efficiency ~ 40%	High operating temperature (200 C), tolerates CO_2 in fuel,
Solid Oxide (SOFC)	Electrolyte of ceramic material (e.g., zirconium dioxide), O^{2-} diffuses through the electrolyte, electric efficiency ~ 65 %	Operates on very high temperatures (1000 C), uses hydrogen or hydrocarbons as fuel (automatic reforming through high temperatures)
Direct Methanol (DMFC)	A polymer electrolyte, a catalyst takes hydrogen directly from the methanol	Low operating temperatures (50 - 100 C), uses methanol as fuel,
Molten Carbonate (MCFC)	Electrolytes of molten salts, still in development phase, automatic reforming	Very high operating temperature (650 C), uses many different fuels

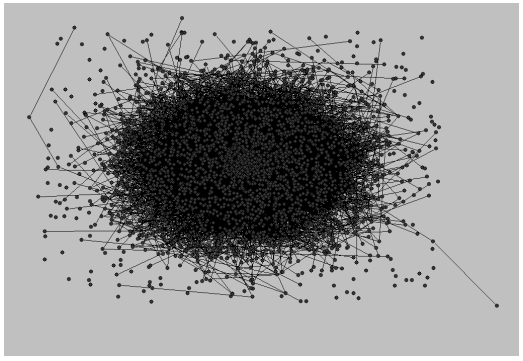
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US patents on fuel cells

- Patent classes 429/12 – 429/46
- 3192 patents are found in the technology classes under consideration, covering the period 1860 – 2002
- Distinct periods: pre-1948 (no citations), 1948 – 1975 (citations not digitized), post-1975 (full citations)

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The full network…



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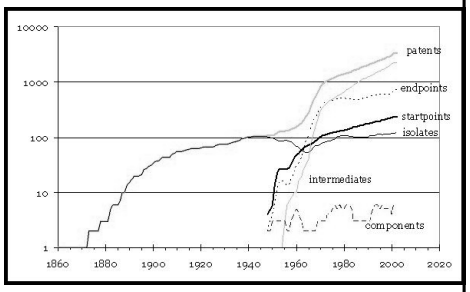
Some statistics

1860-2002

N = 3371

15506 citations

Systematic citations from late 1950s



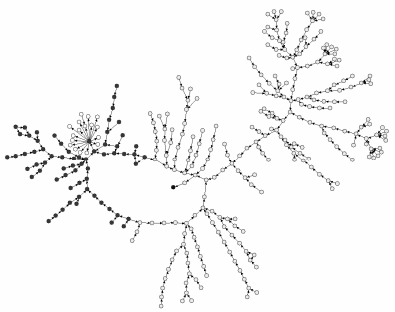
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Top companies/organizations in the field

UNITED TECHNOLOGIES CORPORATION	159	0.05
UNITED STATES OF AMERICA	139	0.04
INTERNATIONAL FUEL CELLS	133	0.04
GENERAL ELECTRIC COMPANY	102	0.03
WESTINGHOUSE ELECTRIC CORP.	88	0.03
LEESONA CORPORATION	85	0.03
SIEMENS AKTENGESELLSCHAFT	84	0.02
UNION CARBIDE CORPORATION	72	0.02
EXXON RESEARCH + ENGINEERING CO.	68	0.02
BALLARD POWER SYSTEMS INC.	58	0.02
FUJI ELECTRIC CO., LTD.	49	0.01
HITACHI, LTD	49	0.01
MITSUBISHI DENKI KABUSHIKI KAISHA	49	0.01
ENERGY RESEARCH CORPORATION	48	0.01
GENERAL MOTORS CORP.	47	0.01
PLUG POWER INC.	39	0.01
ENGELHARD CORPORATION	37	0.01
VARTA AG	37	0.01
INSTITUTE OF GAS TECHNOLOGY	35	0.01
NGK INSULATORS LTD.	34	0.01
AER ENERGY RESOURCES INC.	33	0.01
ALLIS-CHALMERS CORPORATION	30	0.01
MATSHUSHITA ELECTRIC INDUSTRIAL CO., LTD.	30	0.01
ASEA BROWN BOVERI LTD.	28	0.01
RAYOVAC CORPORATION	28	0.01
TOSHIBA CORPORATION	28	0.01
SANYO ELECTRIC CO. LTD.	26	0.01
TEXAS INSTRUMENTS, INCORPORATED	26	0.01
SUM of ABOVE	1641	0.49
OTHERS	1507	0.45

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The network of main paths (based on SPNP) – complete period



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A narrower focus

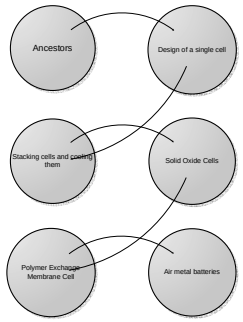
- Within this network of main paths, one may identify a single one as the most important one
  - Based on subjective judgment (H&D, for a small network)
  - Based on cumulative SPNP value

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919022 (1909): W. Jungner (Sweden), "Carbon consuming Galvanic Cell"
2570543 (1951): Pittsburgh Consolidation Coal Company (Gorin), "Conversion of Carbon to Electric Energy"
2581650 (1952): Pittsburgh Consolidation Coal Company (Gorin), "Method of converting Carbon to Electric Energy"
2830109 (1958): Ruhrchemie/SEA (Germany) (Justi), "Fuel cell"
2980749 (1961): Broers (Netherlands), "Fuel cell and method of producing electrodes"
3370984 (1967): Leesona Corporation, "beneficially disposing of the waste heat of the cell"
3436272 (1969): United Aircraft Corp., "manifold arrangement for supplying gases to a fuel cell stack"
3515593 (1970): United Aircraft Corp., "novel bonding means for plates in cooling system"
3761316 (1973): United Technologies (on a contract with the Air Force), "Fuel cell with evaporative cooling"
3923546 (1975): United Technologies, "Corrosion protection for a fuel cell coolant system"
394930 (1976): United Technologies, "Fuel cell cooling system"
4169917 (1979): Energy Research Corp. (on a contract with US Dept. of Energy), "thermal control"
4233369 (1980): United Technologies, (on a contract with US Dept. of Energy) "cooler assembly for fuel cells"
4310605 (1982): Engelhard Minerals & Chemicals (on a contract with US Dept. of Energy", "fuel cell system"
4444851 (1984): Energy Research Corp., "fuel cell stack"
4510212 (1985): Dept. of Energy / Un. of Chicago (Argonne National Laboratory), "core construction for a fuel cell"
4749632 (1988): Dept. of Energy / Un. Of Chicago (Argonne National Laboratory), "Sintering aid for lanthanum chromite refractories"
4910982 (1990): Allied-Signal, "monolithic solid oxide fuel cell"
4988582 (1991): Bell Communications Research, "compact fuel cell"
5242764 (1993): BCS Technology, "Solid Polymer fuel cell"
5472799 (1995): Tanaka KK & Stonehard Associates, "Solid polymer electrolyte fuel cell"
5641586 (1997): University of California (on a contract with the Dept. of Energy), "PEM FC with interdigitated porous flow field
5776625 (1998): H Power Corporation, "proton exchange membrane fuel cell stack"
6068944 (2000): AER Energy Resources", "ventilation system for a metal air battery"
6248464 (2001): Rayovac Corp., "ventilation method for metal air battery"
6355369 (2002): Eontech Group, "ecologically clean air metal battery"

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The main path



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Top companies/organizations on the network of main paths

COMPNAME		Share	ShareTot
UNITED TECHNOLOGIES CORPORAT	28	0.08	0.05
UNITED STATES OF AMERICA	20	0.06	0.04
REVEO, INC.	13	0.04	<0.01
AER ENERGY RESOURCES, INC.	12	0.04	<0.01
EXXON RESEARCH + ENGINEERING	11	0.03	0.02
GENERAL ELECTRIC COMPANY	11	0.03	0.03
UNION CARBIDE AND CARBON CORF	11	0.03	0.02
LEESONA CORPORATION	10	0.03	0.03
ALLIS-CHALMERS MANUFACTURING	7	0.02	0.01
ELTECH SYSTEMS CORPORATION	5	0.01	<0.01
INSTITUTE OF GAS TECHNOLOGY	5	0.01	<0.01
THE STANDARD OIL COMPANY	5	0.01	<0.01

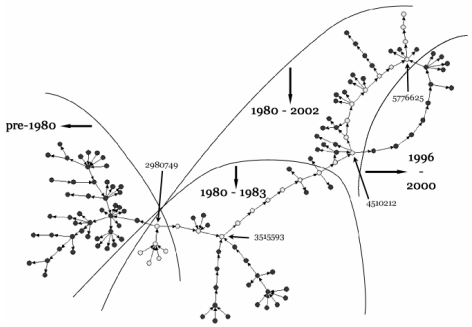
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Broadening again – an historical view

- We can build a network of main paths for 1860 – 1970, one for 1860 – 1980, 1860 – 1985, etc.
- We do this for 1860 – 1960, 1860 – 1961 … 1860 – 2002.
- Within each of these networks of main paths, identify the single most important main path
- Plot the network of all these paths together: this provides a good picture of the historical development of the trajectory

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The evolution of main paths over time



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Conclusions – fuel cells

- Paths are (indeed) selective in the company dimension
- Paths are not internal to the 6 types, but the types have spillovers between them
- Design cycle of levels of aggregation
- A limited number of breaks in the trajectory have occurred (and we can identify the patents that "caused" this)

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Conclusions – methodology

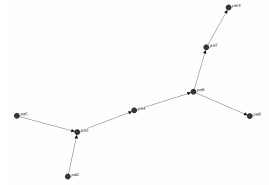
- The method can usefully be applied in combination with an engineering history
  - There is some engineering sense to the results
- A single trajectory for fuel cells may be too broad, we need to look at more paths
  - Methodology extensions proposed here
  - What is the right level of aggregation?

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Terminology (not standardized)

- Edges are the links (citations)
- Vertices (vertex) are the pieces of knowledge (patents)
- Startpoints, endpoints, intermediates, isolates



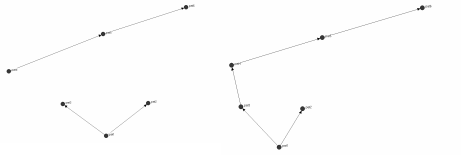
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The notion of a component

- Weak (in the case of directed networks)
- Strong



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