# Time and Space in Knowledge Graphs

Ernest Davis Ontology Summit 2020 May 6, 2020

### Time

## Who is older, Joe Biden or Mitch McConnell?



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## Who is older, Joe Biden or Mitch McConnell?

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	Joe Biden defended his relationship with Mitch McConnell			
	Jun 27, 2019 - He then mentioned Senate Majority Leader Mitch McConnell specifically. By NBC News. WASHINGTON. Joe Biden — who liberal critics say is			
	jacobinmag.com > 2020/02 > joe-biden-history-republi 🔻			
	Joe Biden Has a Long History of Giving Republicans Exactly			
	Feb 29, 2020 - Senate Majority Leader Senator Mitch McConnell and then-vice president Joe			
	Biden in the Old Senate Chamber on Capitol Hill on January 6,			
	www.politico.com > story > 2011/08 > biden-mcconnel 🔻			
	Biden, McConnell and the making of a deal - POLITICO			
	Aug 2, 2011 - Joe Biden and Mitch McConnell are pictured.   AP Photo composite by POLITICO. McConnell and Biden have a long history, serving together			

## Who was on the Supreme Court in 1980?

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#### Justices 1789 to Present - Supreme Court

Name, State App't From, Appointed by President, Judicial Oath Taken, Date Service Terminated. Jay, John, New York, Washington, (a) October 19, 1789, June ...

www.supremecourt.gov > about > biographies 💌

Current Members - Supreme Court

Rehnquist of the Supreme Court of the United States during the 1980 Term. He was Special Assistant to the Attorney General, U.S. Department of Justice from ...

## Who was on the Supreme Court in 1980?

SUPREME COURT IN THE 1980s

Gillian Peele

HE last decade has been an extremely unusual period in the history of the American Supreme Court. For much of the 1980s, Ronald Reagan was President of the United States and his political agenda had a marked impuct on the Supreme Court itself and on the handling of many of the legal controversies which came before the federal courts. It is therefore essential to see American judicial developments not in isolation from the political system but against the broader background of changes in the ideological, political and administrative characteristics of the United States.

#### CHANGING POLITICAL ENVIRON-MENT OF THE COURT

The American Supreme Court was affected by three broad changes in the political system which shaped the way in which its operations would be assessed. The first was the increasingly visible involvement of the courts and the judiciary in a range of public policy areas. Some of this judicial entanglement in areas which in most other systems would have been seen as the proper preserve of the legislature or the ex-

Court's determination to protect civil rights and liberties. From the 1950s onwards the Supreme Court had become involved in such policy areas as discrimination and voting rights; but the range of controversies expanded in the 1980s as governmental agencies and pressure groups as well as individuals sought to clarify or develop the law on topics with implications for the protection of individual freedoms. In addition to cases related to the protections of the Bill of Rights, the Supreme Court found itself drawn into controversies between the different branches of government -for example in relation to the constitutionality of the legislative veto (I.N.S. v. Chadha) and in relation to the constitutionality of the first Gramm-Rudman-Hollings Act (Bowsher v. Synar). At the same time there was a growing corpus of administrative law cases reaching the courts as Congress attempted to regulate agency discretion.

ecutive stemmed from the Supreme

The subject matter of much of the Supreme Court's case-load would have been politically sensitive in any society since it inevitably involved establishing a proper balance between the individual and governmental authority or between the different branches of government. What was increasingly obvious in the United



States however was that many observers felt the federal courts' involvement in the political process had altered in both degree and kind. Certainly in some policy areas (such as education) they had been drawn in to the detailed processes of the management of school systems where critics feared they lacked both competence and legitimacy. Whether this new judicial activitism was justified or not, the important point was that by the 1930s it had

become politically very visible.

The second political change which affected perceptions of the Supreme Court's role in American society in the 1980s was the rise of a powerful conservative movement. This conservative movement had strong links with the Reagan White House and in many areas of policy provided the Reagan administration with ideological inspiration and personnel. What was distinctive about this surge of conservative ideology in America was the extent to which the issues which concerned rightwing activists were 'social' or 'family' issues as much as economic or foreign policy themes. Abortion constituted one of the major social themes addressed by the American conservative movement; but it was also concerned about school prayer, bussing, affirmative action and quotas, pornography, capital punishment and homosexuality. The relevance of this conservative agenda to the Supreme Court in the 1980s was that on virtually every issue of importance to the new right in that period the courts were seen as having handed down decisions which were incompatible with conservative values. Thus the conservative movement believed that any reversal of the liberal trend of judicial decisions required a

### Was Abraham Lincoln alive in 1802?



Was Abraham Lincoln alive in 1802?



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en.wikipedia.org > wiki > Lincoln\_family -Lincoln family - Wikipedia

The Lincoln family includes all the descendants of Abraham Lincoln and Mary Todd Lincoln. ... Mordecai Lincoln (1771–1830) – President Lincoln's uncle on his father's side (saved Lincoln's father's life) ... aunt on his father's side; John Hanks (1802–1889) – President Lincoln's mother's cousin, lived with Lincoln's family for ...

# How many years since the declaration of independence was signed?

G🐾gle

How many years has it been since the declaration of independence was signed ~~ imes

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#### 239 years

239 years since the Declaration of Independence was signed. The US Declaration of Independence was the document that saw the United States break away from rule of the British Government and monarchy. This year it is 239 years since the declaration was signed and brought into govern the United States. Jul 25, 2015

www.warhistoryonline.com > war-articles > 239-years-s... •

239 years since the Declaration of Independence was signed

Q

### Temporal meta-data in Google Books and in Google Scholar are full of errors



#### Alan Turing Reader, University of Manchester Verified email at Isbu.ac.uk - <u>Homepage</u> Mathematics Computer Science Cryptography Artificial Intelligence Morphogenesis

TITLE	CITED BY	YEAR	
Computing machinery and intelligence AM Turing Computers & Thought, 11-35	13473 *	1995	
The imitation game AM Turing Theories of Mind: An introductory reader, 51	13429 *	2006	
The chemical basis of morphogenesis AM Turing Bulletin of Mathematical Biology 52 (1), 153-197	13086 *	1952	
The chemical basis of morphogenesis AM Turing Bulletin of Mathematical Biology 52 (1-2), 153-197	<del>13010</del>	1990	
On computable numbers, with an application to the Entscheidungsproblem: A correction AM Turing Proceedings of the London Mathematical Society 43 (2), 544-546	11138 *	1937	

### Applications of temporal reasoning

#### Text/video understanding

- Narrative
  - Medical records
- Question answering
- Scientific/technological

#### Information retrieval/QA -

• The problem of outdated information.

#### Prediction

Scientific/technological/social

#### Planning

Robotic/Personal/Commercial/Software analysis

In any domain where things change, you have to deal with time. And, to deal with time flexibly and reliably, it's best to have a systematic approach rather than a collection of ad hoc patches.

### State of the art in knowledge graphs (Generally speaking, and as far as I know)

- Many relations that are in fact time-dependent are taken to be atemporal. E.g. the spatial extent of a country.
- Time stamps, when they are there at all, are often "decorations" with little or no semantics.

### Time: Issues to address: Outline

In increasing order of difficulty:

#### Well understood:

- 1. The basic model
- 2. Temporal representations
- 3. Temporal reasoning technology

#### Difficult:

- 4. Collecting temporal information from text
- 5. Indexical expressions in text (i.e. relative to the date of the text)
- 6. Domain inference

### Basic model of time

The basic model of time is the simplest and most reliable in knowledge representation:

• In simple narrative, time is an ordered line isomorphic to the real line.

Comparison, addition, and subtraction suffice for most purpose.

• For counterfactuals and for planning, you additionally need branching time.

That's it.

### Temporal representation

- Situation calculus (McCarthy, Hayes, Reiter): Branching, discrete.
- Interval calculus (Allen): Linear. Order relations on intervals.
- McDermott's temporal logic: Branching, continuous.
- Event calculus (Mueller): Interaction of events and states. Linear.
- Modal temporal logic (Prior, Pnueli).
- Dynamic modal logic (Pratt)

Different things are possible/convenient to represent.

### SotA in temporal representation

Vagueness is an unsolved problem, as throughout KR, and in dealing with language this is a serious limitation. But otherwise:

The purely temporal aspects of practically any situation can be represented.

The purely temporal aspects of most reasoning can be characterized and implemented efficiently.

### Temporal reasoning technology

- Basic time line reasoning simple linear inequalities. Interval algebra.
- High level planning.
- Temporal data bases.
- Program verification. In many ways, immensely powerful. Can deal with complexities such as:
  - Subtle side-effect relations
  - Conditionals and loops
  - Asynchronous parallelism

### Wide range of scales

A six-month trip involves actions of 1/10 of a second. Ratio: 1.5\*10<sup>8</sup>

It may involve reasoning about distances ranging from 1 mm to 10,000 km. Ratio:  $10^{10}$ 

This becomes an issue for a number of different kinds of algorithms and representations.

## Extracting temporal information from text

 Time relations between generic/repeated/ongoing/hypothetical events are difficult to characterize and left implicit.

"Afraid of Covid-19, parents are postponing well-child checkups, including shots, putting millions of children at risk of exposure to preventable deadly diseases." NY Times, April 23, 2020

• Events are stated out of order.

"Tony managed to pour the wine, though he had to take out the cork with a knife, because he couldn't find the corkscrew."

### Indexical expressions in text

The majority of time references are indexical.

"Last week", "At 2:00 today", "Next Tuesday", past vs. present vs. future.

Indexicals in conversation, or in the question of a Q/A system almost always refer to the current moment. That should be easy.

Indexicals in a text or a recording generally refer to the time of writing/utterance. But there are exceptions, e.g. within quotations.

Placing in an absolute time line requires finding the date of the text/utterance.

This can range from trivial (if dated) to extremely difficult (if not).

## Extracting temporal relation from video

If video time = real time, then trivial.

Else (finding the time relation between two consecutive scenes in a film) extremely difficult in general.

### Domain-specific inference

Older(x,y) iff BirthOf(x) < BirthOf(y).

If Holds(t,Alive(x)) then BirthOf(x)  $\leq$  t  $\leq$  DeathOf(x)

The background knowledge in the wine-pouring examples and in the vaccination example are much harder to characterize.

### Take away for Time

- Extremely important problem in many AI situations.
- Some aspects are straightforward, others are Al-complete.
- A lot more could pretty easily be done with existing technology than is currently being done. A lot can be done with very short inference paths, either at query time or at fact addition time.
- Obsolete and outdated information in knowledge sources is a serious issue.
- In designing a knowledge graph, one should consider from the start what kind of temporal knowledge to include and how it can be used. Ignoring time and doing everything in the timeless present is often easy, but may not be wise.

## Space

## How far is the border of Mexico from San Diego?



how far is the border of mexico from san diego?		
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## How far is the border of Mexico from San Diego?



### How far is the boundary of Mexico from S **WolframAlpha** Computational

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### Applications of spatial reasoning

- Physical reasoning: Science and technology
  - Prediction
  - Explanation
  - Design
  - Planning
- Robotics
- Computer vision

### Space: Issues to address: Outline

In increasing order of difficulty:

### Well understood:

- 1. The basic model
- 2. Geographic information in knowledge bases
- 3. Spatial representations for exact information
- 4. Geometric calculations with exact information **Difficult:**
- 5. Representation and reasoning with partial information
- 6. Extracting spatial information from data
- 7. Domain inference

### Basic model of space

- Three-dimensional Euclidean space. R<sup>3</sup>
- A points is a point in R<sup>3</sup>
- A region is a "well-behaved" set of points.
- Other spatial entities are other kinds of sets of points, functions over points, etc.

## Exact information: representation and computation

Point: Coordinates relative to a coordinate system Regions: There are many representations:

- Point cloud
- Voxels
- Constructive solid geometry
- Mesh representation.

Etc. Depends on desirable features, computations to be performed, physical device.

Challenging algorithmic problems. Many algorithms, much software.

## Geographic knowledge in knowledge bases

- Location of the geographic center.
- Bounding box. Extremes of latitude and longitude.
- Specific measures e.g. area.
- Containment relations. Bordering relations.
- Maps as images.

Sufficient for some purposes (e.g. flight distance between cities).

Sophisticated systems like Wolfram Alpha certainly record more information, but are uneven in the degree that they use them.

### Florida geography in Wikipedia infobox

Coordinates: 🍋 28.1°N 81.6°W

Florida			
Area			
Total	65,757.70 <sup>[2]</sup> sq mi		
	(170,312 km <sup>2</sup> )		
Area rank	22nd		
Dimensions			
Length	447 mi (721 km)		
• Width	361 mi (582 km)		
Elevation	100 ft (30 m)		
Highest elevation (Britton Hill <sup>[3][4]</sup> )	345 ft (105 m)		
Lowest elevation	0 ft (0 m)		
(Atlantic Ocean <sup>[3]</sup> )			
Latitude	24° 27' N to 31° 00' N		
Longitude	80° 02' W to 87° 38' W		

### Incomplete or generic information



- 8" scale: Frustum of a pyramid.
- 3": Handle
- 1/4'': Holes
- 1/8'': Lip at hole
- 1/20'': Sharp blade at lip

Topology: Holes go through grater connecting outside with cavity.

Repeated pattern of holes

### Incomplete or generic information

- If you turn a coffee cup upside down, the coffee will pour out.
- A physics engine can do this (not as easily as you might suppose) if it has exact specifications of:
- The shape of the cup
- The turning motion
- The amount of coffee in the cup

You want to use this inference in multiple directions: e.g. if you are holding a cup upside down then it is empty.

### Incomplete or generic information



String bag is flexible though not elastic, so there is a lot of possible variation in overall shape.

Peppers will stay in the bag. Peas will fall through the holes. Elephants will not fit in the bag.

Regular structure of strings and knots.

#### Representation and reasoning: A large gap between the theory that exists and the technology we need

There are systematic representations and reasoning techniques for specific qualitative spatial relations; e.g. part-whole relations; topological relations; direction between points in the plane; etc

But these are largely mathematics in (not very successful) search of applications.

There is no systematic representation for the significant qualitative features of the cheese grater or the string bag; let alone a reasoning mechanism for them. There are not even any good benchmark sets.

### Extracting information from data

#### Natural language.

Notorious terrible for spatial information – especially shape, but also relative position. "A picture is worth 1000 words."

Spatial pronouns are ambiguous.

- "coffee in the cup."
- "milk in the coffee."
- "a nail in the wall."
- "bones in the foot."
- "a car in the parking lot."
- "a dent in the door."
- "a bend in the road" ...

## Vision, images, video and measurement

- Provide precise (often incomplete) information about specific situations, but not generic.
- Extracting spatial relations is an understudied problem in vision.

Lots of vision systems identifies that as a man and can plausibly fill in his right side.

AFAIK, no current vision system infers that he is standing behind a barrier.



### Domain inference

From the fact that a bottle is leaking

infer that it has a hole.

From the fact that a person walks from A to B in five minutes

infer that they are less than half a mile apart. From the fact that a birthday present is in a small box infer that it might be jewelry.

### Takeaways for Space

Often an important question in applications.

When precise information is available and pertinent (often for geographic information; sometimes otherwise), there is a range of options. Consider with some care.

Keep an eye out for situations where incomplete information is significant. Do not simply recast them in terms of complete information. I would be interested to hear about them.

## Thank you!

## COMET (Yejin Choi and colleagues at Allen Institute for AI)

**Input:** PersonX ate a hot dog:

### Sample outputs:

Because PersonX wanted to be full.

Before, PersonX needed to buy a hot dog.

*PersonX is seen as* hungry.

PersonX is seen as satiated.

As a result PersonX wants to drink water.

As a result, others feel full.

https://mosaickg.apps.allenai.org/comet\_atomic