Artificial Intelligence Applied to the Web

Chapter 3 Part 3 - Modern Web Search Approaches

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Outline

Modern Web Search Approaches

Motivation

The Current State of Search

- The search box has become the default user interface for interacting with data in most modern applications.
- We not only search explicitly, but also consume content streams customized to our tastes and interest.
- The concept of a “search engine” goes beyond websites like Google; it is present in nearly all our digital interactions.

Motivation

The Impact of LLMs and New Expectations

- The arrival of technologies like ChatGPT, Claude, and Gemini has skyrocketed expectations for the intelligence level of search technologies.
- Users no longer expect just a list of “ten blue links”, but a much more sophisticated search experience.
- These Language models are being actively integrated into major search engines, influencing their evolution.

Motivation

User Expectations for Current Search Technology

Users today expect search technology to be:

- **Domain-aware**: It should understand entities, terminology, and categories specific to the user case, not just generic text statistics.
- **Contextual and personalized**: It should take into account user context (location, previous searches, profile) and domain context (inventory, business rules) to better interpret intent.
- **Conversational**: It should be able to interact in natural language and guide users through a multi-step discovery process.

Motivation

User Expectations for Current Search Technology

- **Multi-modal**: It should be able to resolve queries issued by text, voice, or images, and search across these different content types.
- **Intelligent**: It should deliver predictive type-ahead, understand what users mean (spelling correction, intent classification), and constantly get smarter.
- **Assistive**: It should move beyond delivering links to provide direct answers, summaries, explanations, and available actions.

Motivation

The Critical Role of the Search engine in Modern AI

- Even the best conversational AI models can "hallucinate" (make up bad answers) if they are not tethered to a reliable information source, such as a search engine index.
- **Retrieval Augmented Generation** (RAG) emerges as the stardard technique to ground AI systems.
- In RAG, a search engine or vector database is used as a knowledge source to provide LLMs with accurate and up-to-date information as context.

Motivation

The Goal of AI-Powered Search

- The goal is to use automated machine learning techniques to deliver on all the desired search capabilities (domain-aware, contextual, conversational, etc.).
- While many organizations spend years manually tuning their systems, AI-Powered Search aims to automate most of that process.

What is AI-Powered Search?

Fundamental Definitions

- **Artificial Intelligence (AI)**: In the context of software development, AI generally describes any computer program that can perform a task that previously required human intelligence.
- **Search**: Refers to any technology that enables users to query for and find information. It involves two critical steps:
  - **Matching**: Finding documents that match a query.
  - **Ranking**: Ordering those documents by relevance to the query.

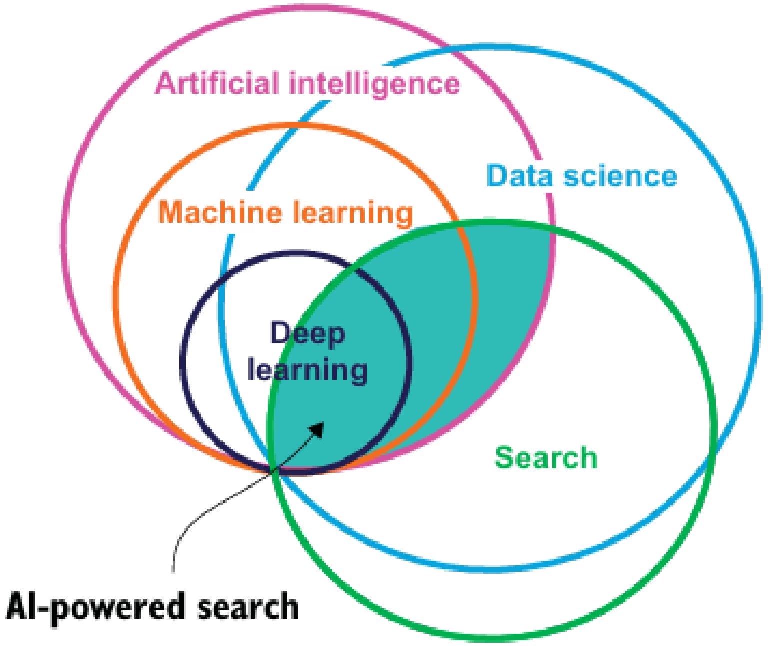
What is AI-Powered Search?

A Conceptual Diagram

- **AI-Powered Search** is the intersection of the fields of search (information retrieval) and Artificial Intelligence.
- The relationship between key disciplines is as follows:
  - **Machine Learning (ML)**: A subset of AI that use data to train models to perform tasks.
  - **Deep Learning (DL)**: A further subset of ML that focuses on training artificial neural networks.
  - **Data Science**: A discipline that heavily overlaps with both AI and search but is not a complete subset of either.

What is AI-Powered Search?

A Conceptual Diagram

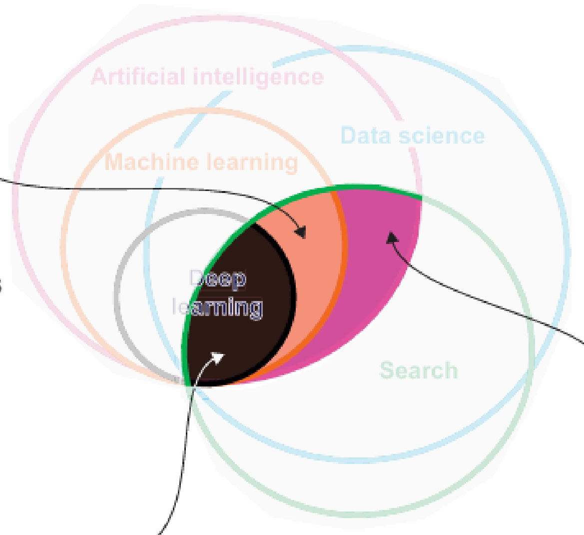


What is AI-Powered Search?

Specific AI-Powered Search Techniques

Machine learning (ML):

- **Signals boosting models**
- **Learning to rank**
- **Semantic search**
- **Collaborative filtering**
- **Personalized search**
- **Content clustering**
- **NLP/entity resolution**
- **Semantic knowledge graphs**
- **Document classification**
- ***Deep learning***
- **Etc.**



Artificial intelligence (AI):

- **Question/answer systems**
- **Virtual assistants**
- **Chatbots**
- **Rules-based relevancy**
- ***Machine learning***
- **Etc.**

Deep learning (DL):

- **Foundation models/LLMs**
- **Neural search/vector search**
- **Word embeddings**
- **Multimodal search (image, video, etc.)**
- **Generative search and summarization**
- **Etc.**

What is AI-Powered Search?

Specific AI-Powered Search Techniques

- **AI-only category**:
  - Includes AI techniques that are often build using machine learning but do not fundamentally require it.
  - Examples of these techniques include question-answering systems, virtual assistants, chatbots, and rules-based relevancy.
  - It is possible to build chatbots based entirely on rules to understand user intents, and question-answering systems can function solely on rules and ontologies.
  - However, the lines between categories are often blurred because machine learning is frequently used to **learn these types of rules and ontologies**.

What is AI-Powered Search?

Specific AI-Powered Search Techniques

- **Machine Learning category**:
  - This subcategory begins when algorithms start using data to train models.
  - It uses **behavioral signals** from users (clicks, likes, purchases, etc.) to build models that learn to better rank documents.
  - ML is also used to learn **knowledge graphs** to better understand the domain and interpret user queries.
  - This enables **semantic search** through knowledge graphs and other natural language processing techniques.

What is AI-Powered Search?

Specific AI-Powered Search Techniques

- **Deep Learning category**:
  - Involves the use of neural networks to build models that can understand user queries and documents, as well as rank and summarize search results.
  - Text is used to train LLMs to understand the meaning of words and phrases, generate answers, and create summaries.
  - LLMs are a type of model that interprets text content, often trained on massive amounts of text from the internet. Can also be trained on images, audio, or video to enable **multimodal search** (e.g., text-to-image).

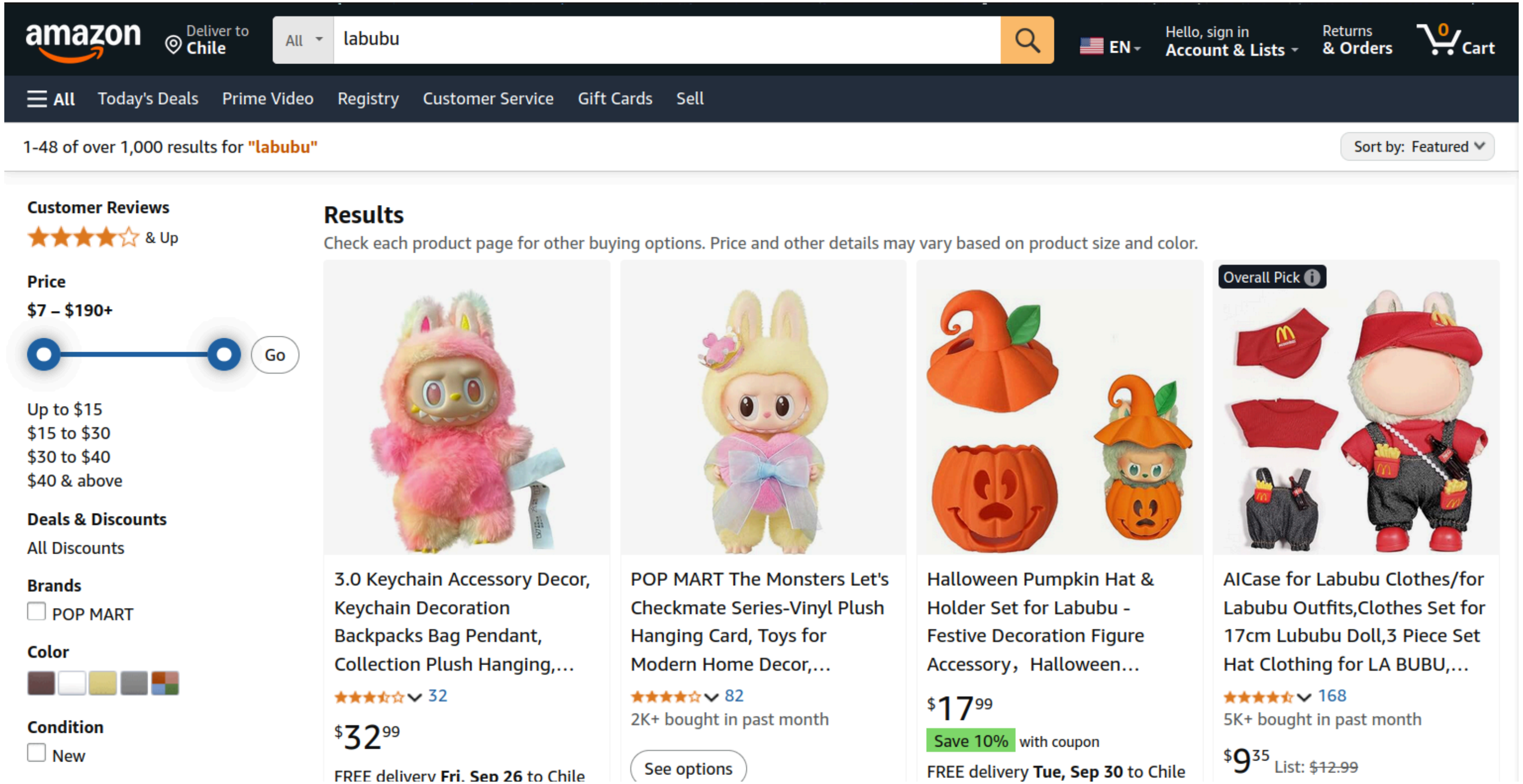
Understanding User Intent

Search Engine vs Recommendation Engines

- **Search Engine**:
  - Typically thought of as a technology for explicitly entering queries and receiving a response.
    - Usually exposed via a text box direct discovery of content.
- **Recommendation Engine**:
  - Typically does not accept direct user input.
  - Delivers content based on what the engine learns about users, calculating best matches for their interest and behaviors.
  - Commonly uses three approaches: content-based, behavior-based, and multimodal recommenders.

Understanding User Intent

Search Engine

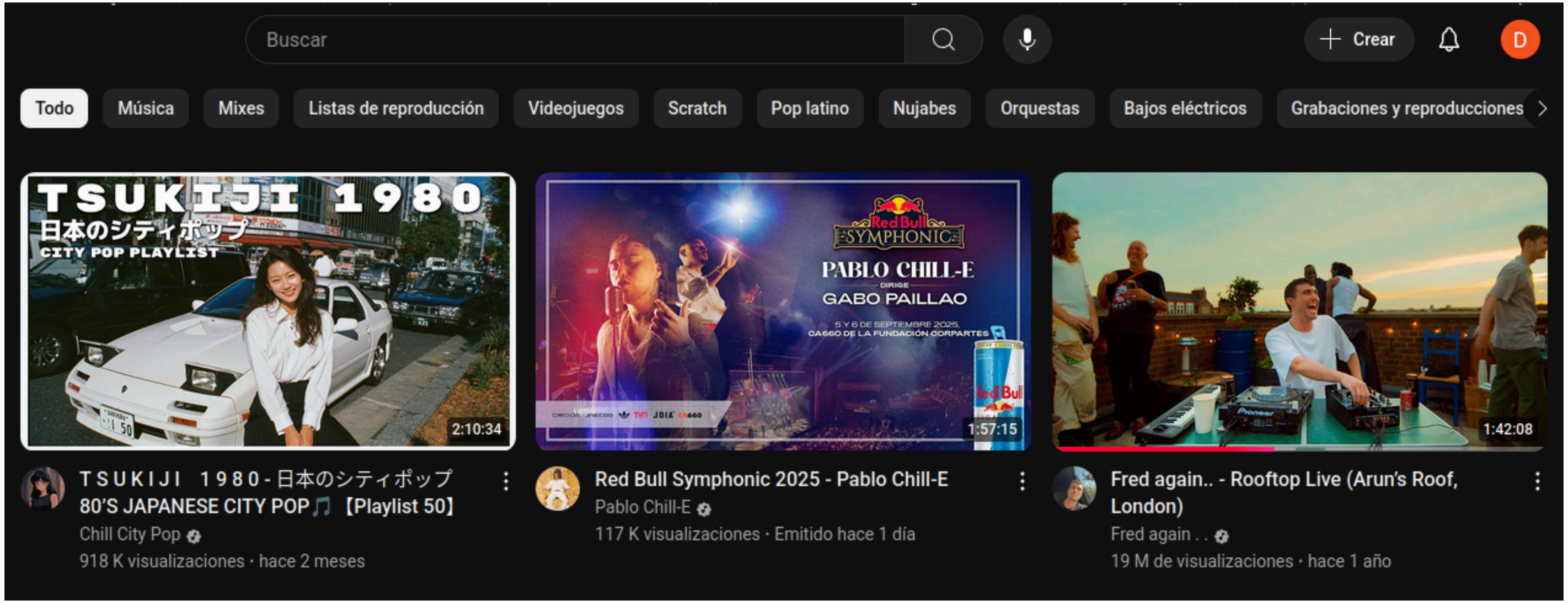


Understanding User Intent

Recommendation Engine

Understanding User Intent

Recommendation Engine



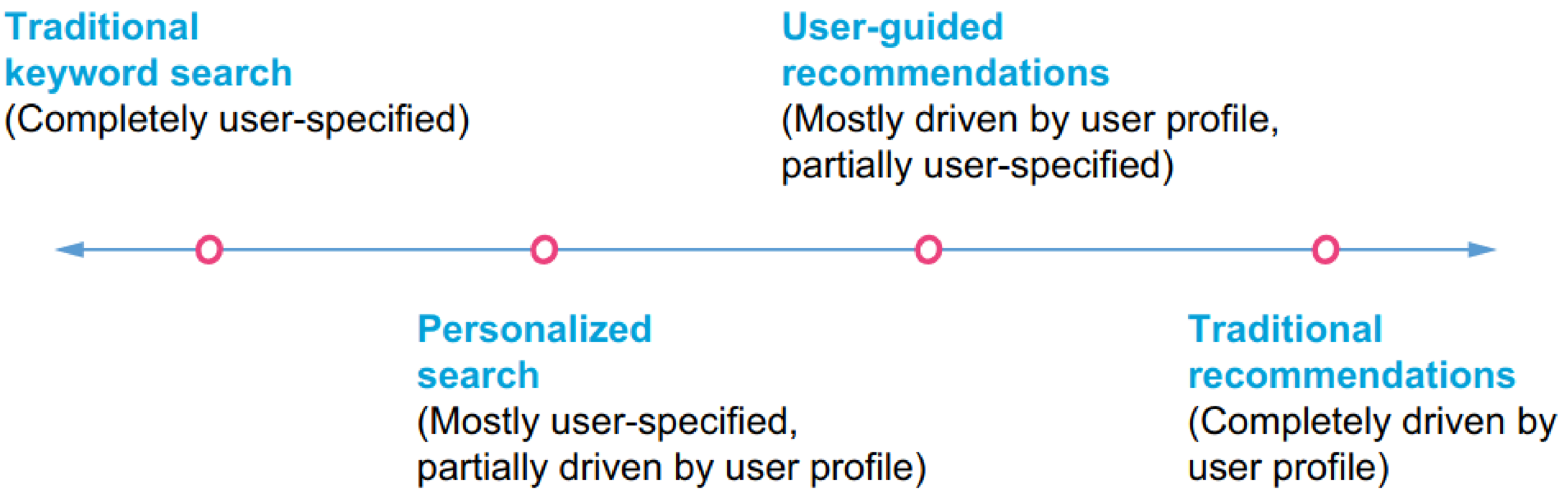
Understanding User Intent

The Personalization Spectrum

- Search and recommendation engines are not separate systems but two sides of the same coin.
- The goal in both cases is to understand a user's information need and deliver relevant results.
- They exist on a spectrum of personalization:
  - **Traditional Keyword Search**: Completely user-specified.
  - **Personalized Search**: Mostly user-specified, partially driven by user profile.
  - **User-Guided Recommendations**: Mostly driven by user profile, partially user-specified.
  - **Traditional Recommendations**: Completely driven by user profile.

Understanding User Intent

The Personalization Spectrum



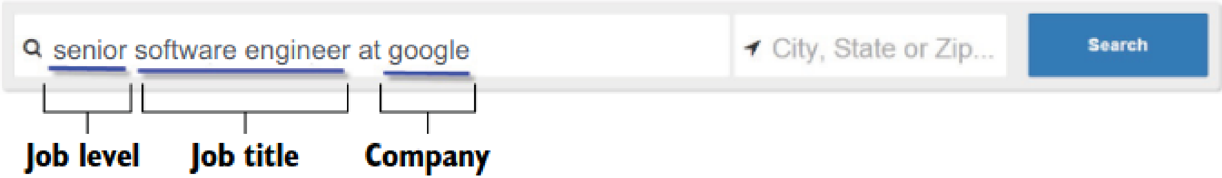
Understanding User Intent

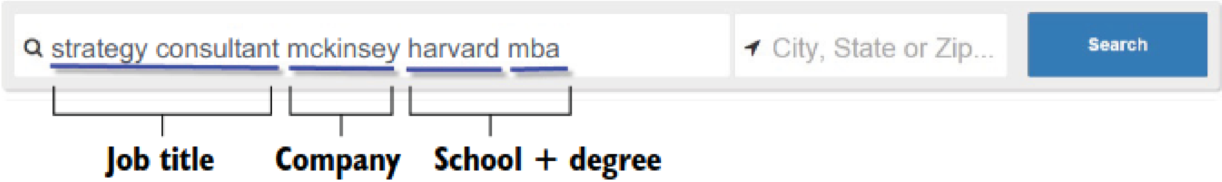
The Third Dimension: Domain Understanding

- It is not enough to just match keywords and recommend based on user interactions; the engine must also deeply understand the specific domain.
- This includes:
  - Learning all important domain-specific phrases, synonyms, and related terms.
  - Identifying entities in documents and queries.
  - Generating a knowledge graph that relates those entities.
  - Disambiguating the many nuanced meanings of domain-specific terminology.
- The ultimate goal is to **search on “things”, not “strings”.**

Understanding User Intent

The Third Dimension: Domain Understanding





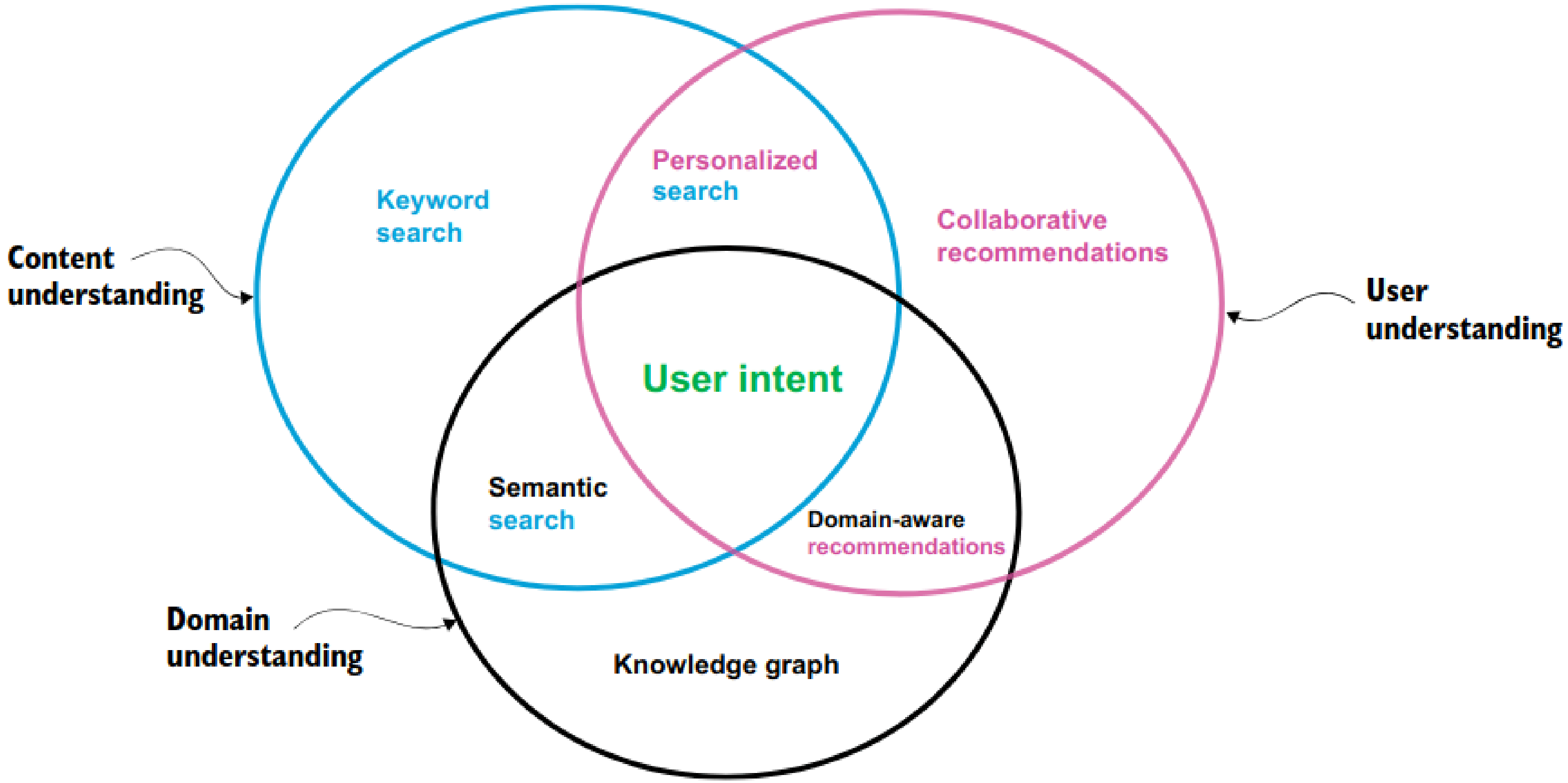
Understanding User Intent

The Three Pilars of User Intent

- To truly understand user intent, an AI-powered search system need to combine three key pilars:
  - **Content Understanding**: The ability to find the right content based on keywords, language patterns, and attributes. This corresponds to traditional keyword search.
  - **User Understanding**: The ability to understand each user's specific preferences to return more personalized results. This corresponds to collaborative recommendations.
  - **Domain Understanding**: The ability to interpret words, phrases, concepts, entities, and relationships within your domain-specific context. This is powered by a knowledge graph.

Understanding User Intent

Achieving True User Intent



Understanding User Intent

Achieving True User Intent

- The intersection of these pillars create more advanced search capabilities:
  - Content + User Understanding: **Personalized Search**.
  - Content + Domain Understanding: **Semantic Search**.
  - User + Domain Understanding: **Domain-Aware Recommendations**.
- The "holy grail" for AI-powered search is to harness the intersection of all three categories. This requires:
  - An expert understanding of the domain.
  - An expert understanding of the users and their preferences.
  - And expert ability to match and rank arbitrary queries against any content.

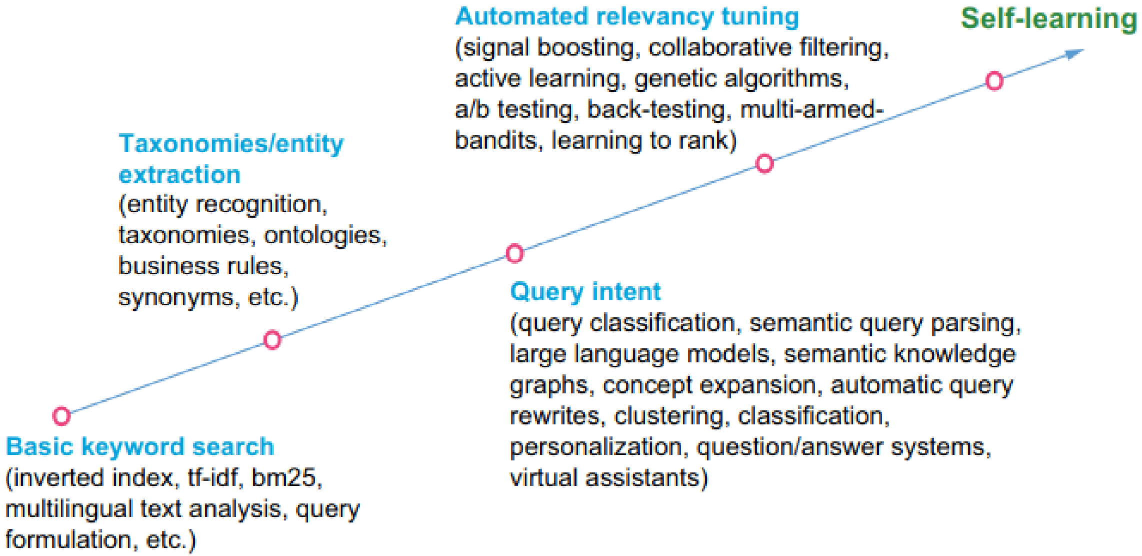
How AI-Powered Search Works

The Search Intelligence Progression

- Search intelligence typically matures along a predictable path.
- The stages of this progression are:
  - **Basic keyword search**: The typical starting point, using foundational algorithms like inverted index.
  - **Taxonomies/entity extraction**: Manually injecting domain understanding with synonyms, taxonomies, ontologies, and business rules.
  - **Query intent**: Focusing on correctly interpreting user queries through classification, semanting parsing, and knowledge graphs.
  - **Automated relevancy tuning**: Automating the tuning process through learning from user signals, A/B testing, and building machine-learning models.
- The end goal is a completely automated, **self-learning** engine.

How AI-Powered Search Works

The Search Intelligence Progression



How AI-Powered Search Works

Reflected Intelligence through feedback loops

- Feedback loop are critical to building an AI-powered search solution.
- Without feedback, it's like an education consisting only of reading textbooks with no teachers, exams, or classmates, which would lead to a flawed understanding.
- Traditional search engines often operates this way, acting on their initial configurations the same way every time for repeated user queries.
- However, search engines are the perfect type of system for interactive learning when feedback loops are introduced.

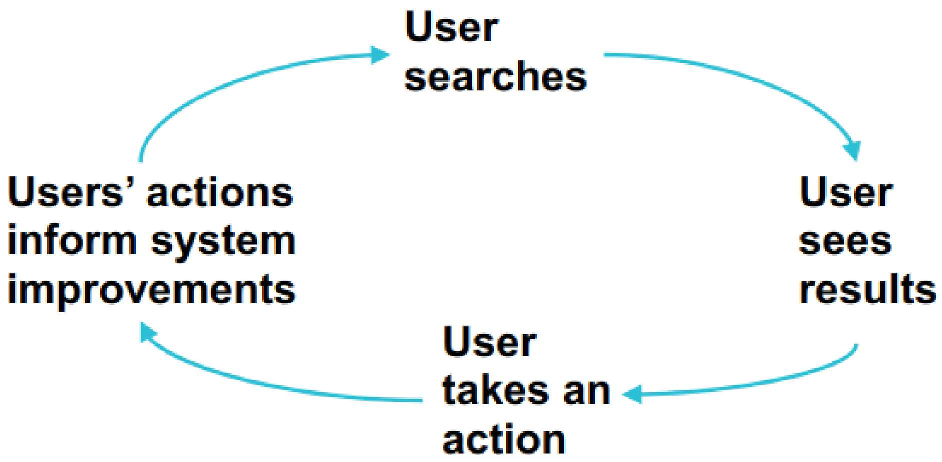
How AI-Powered Search Works

The Flow of a Search Feedback Loop

- Step 1: A user issues a query. This query executes a search.
- Step 2: The system return results. These can be specific answers, a list of answers, or links to pages.
  - Step 3: The user takes one or more actions.
    - These actions usually start with clicks on documents.
    - They can lead to other context-specific actions, such as:
      - Adding an item to a shopping cart and purchasing it.
      - Giving an item a thumbs up or thumbs down.
      - Liking or commenting on the result.

How AI-Powered Search Works

The Flow of a Search Feedback Loop



These actions can then be used to generate an improved relevance ranking model for future searches.

How AI-Powered Search Works

The Power of Signals

- User interactions like searches, clicks, likes, add-to-carts, and purchases are collectively referred to as **signals**.
- Signals provide a constant stream of feedback that can be used by machine learning algorithms to power user, content, and domain understanding.

How AI-Powered Search Works

The Power of Signals

- Key refelected intelligence algorithms powered by signal include:
  - **Popularized relevance**: Signals-boosting algorithms use aggregated signals to boost the rankings of the most important documents for popular queries.
  - **Personalized relevance**: Collaborative filtering algorithms use signals to generate recommendations and user profiles to personalize search results.
  - **Generalized relevance**: Learning to rank algorithms train ranking classifiers based on relevance judgments generated from user signals to create models that can apply to all queries.

How AI-Powered Search Works

The Power of Signals

Signal collection & processing

pizza

User searches

User sees results

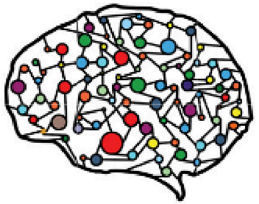
User takes an action

Users' actions inform system improvements

User	Query	Results
Alonzo	**pizza**	doc10, doc22, doc12, …
Elena	**soup**	doc84, doc2, doc17, …
Ming	**pizza**	doc10, doc22, doc12, …
…	…	…

User	Action	Document
Alonzo	**click**	doc22
Elena	**click**	doc17
Ming	**click**	doc12
Alonzo	**purchase**	doc22
Ming	**click**	doc22
Ming	**purchase**	doc22
Elena	**click**	doc2
…	…	…

Learned relevance models



Signal processing & machine learning

How AI-Powered Search Works

Content and Domain Intelligence

- While signals provide usage data, the **content** is also a rich source of information for feedback loops.
- The content of the documents forms a representative textual model of your domain.
- **Large Language Models** (LLMs) based on the **Transformer architecture** have revolutionized query and content interpretation.
  - They are deep neural networks trained on massive amounts of text.
  - They can recognize, summarize, predict, and generate new data.
  - They are used to generate **embeddings**, which are numerical vector representations of content's meaning, enabling a sophisticated ability to search on a query's meaning.

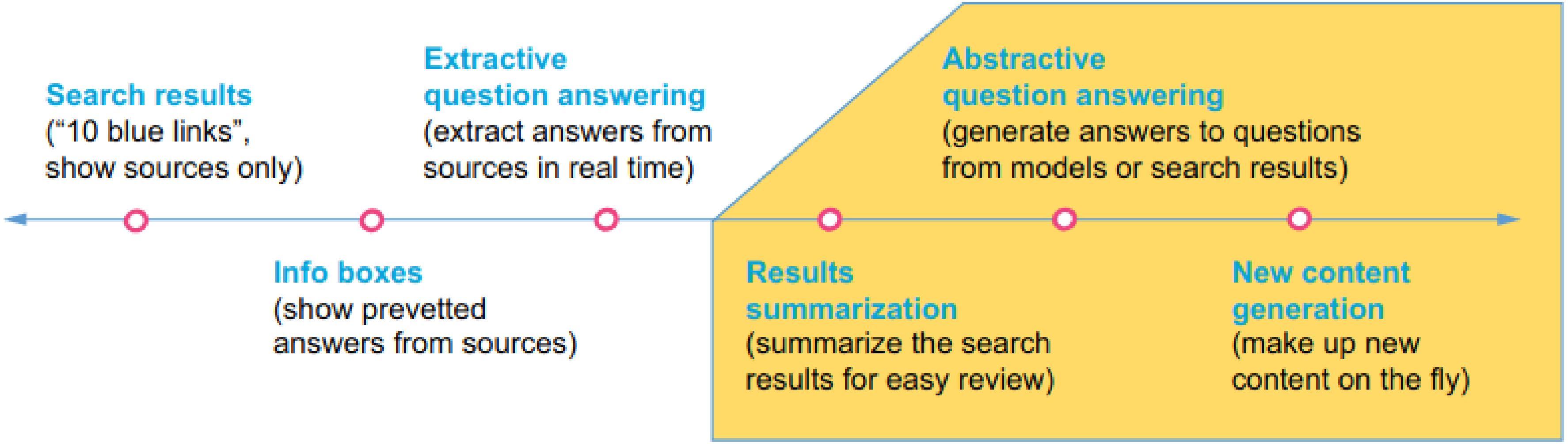
How AI-Powered Search Works

Generative AI & Retrieval Augmented Generation (RAG)

- Generative AI and AI-powered search are tightly intertwined.
- **Retrieval Augmented Generation (RAG)**: Search engines are used as a knowledge source for LLMs, allowing relevant context to be retrieved and passed to the LLM to ensure it has up-to-date and accurate data from which to answer. This is critical for preventing LLMs from "hallucinating".
- **Generative Search**: In turn, LLMs are critical components of search engines. They can be used to:
  - Interpret queries and generate embeddings.
  - Generate summaries of search results.
  - Generate answers to questions directly from search results.

How AI-Powered Search Works

Generative AI & Retrieval Augmented Generation (RAG)



How AI-Powered Search Works

Architecture for an AI-Powered Search Engine

- An end-to-end system for continuous learning requires several key building blocks:
  - A **core search engine** (indexing, matching, ranking).
  - **Index-time transformations** to enrich content as it's indexed (e.g., creating embeddings, extracting entities).
  - **Query pipelines** to interpret incoming queries (e.g., correcting misspellings, expanding with synonyms, rewriting the query).
  - A **job processing framework** to run batch jobs on content and signals to derive domain-specific intelligence.
  - A mechanism for **collecting the constant stream of user signals**.
  - Generated **models** that are used to constantly adjust future search results.

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