WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

CS639: Data Management for Data Science

Lecture 3: Principles of Data Management

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Announcements

- Mix-up with due dates ☹ It should be fixed now.
    - No changes to the midterm
- Updates and hints on PA1 assignment on Piazza
- Questions?

Today’s Lecture

1. Data Management

2. Data Models

3. RDBMs and the Relational Data Model

1. Data Management

Data Management

- Data represents the **traces** of real-world processes.
- Data is valuable **but** hard and costly to manage
  - Storage, representation complexity, collection
- Data management seeks to answer two questions:
  - What operations do we want to perform on this data?
  - What functionality do we need to manage this data?

Required Functionality

- Describe real-world entities in terms of stored data
- Create & persistently store large datasets
- Efficiently query & update
  - Must handle complex questions about the data
  - Must handle sophisticated updates
  - Performance matters
- Change structure (e.g., add attributes)
- Concurrency control: enable simultaneous queries, updates etc
- Crash recovery
- Access control, security, integrity

It is difficult and costly to implement all these features!

Systems providing data management features

- Relational database management systems
- HDFS-based systems (e.g., hadoop)
- Stream management systems: Apache Kafka
- Others?

BIG DATA LANDSCAPE 2017

INFRASTRUCTURE

HADOOP ON-PREMISE
cloudera, Hortonworks, MAPR, Pivotal, IBM InfoSphere, bluedata, jethro

HADOOP IN THE CLOUD
amazon web services, Microsoft Azure, Google Cloud Platform, IBM InfoSphere BigInsights, TREASURE DATA, Qubole, altiscale, CAZENA, CenturyLink

STREAMING / IN-MEMORY
amazon web services, databricks, confluent, striim, GridGain, METAMARKETS, DATATORRENT, dataArtisans, ORACLE Coherence, hazelcast, TERRACOTTA

NOSQL DATABASES
Google Cloud Platform, ORACLE, amazon DynamoDB, Microsoft Azure, MarkLogic, mongoDB, DATASTAX, AEROSPIKE, Couchbase, redislabs, influxdata

NEWSQL DATABASES
SAP HANA, Clustrix, Pivotal, NUODB, memsql, splice MACHINE, MariaDB, VOLTDB, citusdata, Trafodion, deepdb, paradigm4

GRAPH DBS
neo4j, IBM, ORACLE, OrientDB, InfiniteGraph, Objectivity

MPP DBS
TERADATA, VERTICA, NETEZZA, Actian, kognitio, EXASOL, dremio

CLOUD EDW
amazon web services, Google Cloud Platform, Microsoft Azure, Pivotal, snowflake, Infoworks

DATA TRANSFORMATION
talend, pentaho, alteryx, TRIFACTA, tamr, Paxata, StreamSets, UNIFI

DATA INTEGRATION
informatica, MuleSoft, snapLogic, TEALIUM, Segment, enigma, podium data, alooma, ZALONI, xplenty, import.io, Stitch

DATA GOVERNANCE
informatica, IBM, skyhigh, collibra, Alation, Waterline Data

MGMT / MONITORING
amazon web services, New Relic, APPDYNAMICS, actifio, DATADOG, WAVEFRONT, splunk, unravel, Anodot, Pepperdata, rocana, Numerify, pagerduty

STORAGE
amazon web services, Google Cloud Platform, Microsoft Azure, ALLUXIO, nimblestorage, Qumulo, COHO, panasas

CLUSTER SERVICES
amazon web services, kubernetes, docker, MESOSPHERE, CoreOS, pepperdata

APP DEV
Lightbend, Keen IO, rainforest, CASK

CROWDSOURCING
amazon mechanical turk, Upwork, WorkFusion, CrowdFlower

HARDWARE
Google TPU, ARM, nervana, Graphcore, MYTHIC, cerebras, NVIDIA, Movidius, SCORTEX

ANALYTICS

DATA ANALYST PLATFORMS
Microsoft, pentaho, alteryx, Digital Reasoning, GUAVUS, AYASDI, MATTIVO, Datameer, Quid, ClearStory, OrigamiLogic, interana, Bottlenose, ARIMO, ENDOR, MODE

DATA SCIENCE PLATFORMS
IBM, KNIME, dataiku, DOMINO, yhat, rapidminer, CONTINUUM ANALYTICS, Alpine, Angoss, ALGORITHMIA

BI PLATFORMS
Microsoft, DOMO, amazon web services, salesforce, looker, Wave Analytics, atscale, ARCADIA DATA, GoodData, SISENSE

VISUALIZATION
tableau, SAP, Google Cloud Platform, Qlik, celonis, MAPD, Periscope, ZEPL, CHARTIO, plotly, DOMATA

VERTICAL ANALYTICS
PREDIX, C3 IoT, CAPE, UPTAKE, Orbital Insight, TACHYUS, Alluvium, datarama

STATISTICAL COMPUTING
sas, SPSS, MATLAB

DATA SERVICES
Palantir, Mu Sigma, OPERA, DATA SCIENCE, kaggle, Fractal, EXL, DataKind, FF

MACHINE LEARNING
Azure Machine Learning, amazon web services, Google Cloud Platform, H2O.ai, DataRobot, VISENZE, context relevant, bonsai, DATARPM, deepsense.io, tonian

HORIZONTAL AI
IBM Watson, Cortana, Face++, sentient, Voyager Labs, vicarious, clarifai, Affectiva, CognitiveScale, SENSETIME, Numenta, Cronocam, OSARO, PETUUM, nara, CURIOUS AI, BLUE VISION

SPEECH & NLP
Google Cloud Platform, twilio, amazon alexa, Narrative Science, semantic machines, Wolfram Alpha, MindMeld, ARRIA, NUANCE, iDIBON, TalkIQ, maluuba, snips, cortical.io, sayso, Gridspace, SoundHound Inc.

SEARCH
Autonomy, elastic, ORACLE ENDECA, EXALEAD, ThoughtSpot, Algolia, Lucidworks, swiftype, MAANA, alphasense, SearchInk, SINEQUA

LOG ANALYTICS
splunk, sumologic, loggly, kibana, logz.io

SOCIAL ANALYTICS
Hootsuite, sprinklr, NETBASE, DATASIFT, tracx, synthesio, simplereach, bitly, predata

WEB / MOBILE / COMMERCE ANALYTICS
Google Analytics, mixpanel, AMPLITUDE, sumAll, Airtable, retention science, SIGOPT, granify, custora

APPLICATIONS – ENTERPRISE

SALES
einstein, CHORUS, INSIDESALES.COM, conversica, Gong, clari, AVISO, TACT, fuse machines, TROOPS

MARKETING - B2B
RADIUS, App Annie, EVERSTRING, Lattice, infer, MINTIGO, 6sense, tubular, Reflektion, DataFox, NGAGIO

MARKETING - B2C
Zeta, bloomreach, blueyonder, PERSADO, kahuna, ACTIONIQ, BLUECORE, SAILTHRU, QUANTIFIND, mparticle, Amplero

CUSTOMER SERVICE
MEDALLIA, zendesk, Gainsight, CLARABRIDGE, CLICKFOX, NGDATA, DigitalGenius, appuri, AUTOMAT, frame.ai, msg.ai, INTERCOM

HUMAN CAPITAL
HireVue, entelo, hiQ, GIGSTER, textio, RESTLESS BANDIT, Wade&Wendy, Clustree, Stella, pymetrics

LEGAL
RAVEL, Seal, Everlaw, JUDICATA, Brevia, ROSS, casetext

FINANCE
anaplan, Zuora, tidemark, SAP S/4 HANA, TRADESHIFT

ENTERPRISE PRODUCTIVITY
slack, facebook, X.ai, ORACLE, lumiata, diffbot, Clara, talla, butter.ai, KASISTO

BACK OFFICE AUTOMATION
HyperScience, Captricity, AppZen

SECURITY
TANIUM, CYLANCE, StackPath, illumio, CODE42, DARKTRACE, ThreatMetrix, DataGravity, cybereason, VECTRA, CipherCloud, Guardian Analytics, SIGNIFYD, ANOMALI, siftscience, SentinelOne, SecurityScorecard, BlueTalon, Recorded Future, feedzai, sqrrl, SOCURE, AREA 1 SECURITY, FORTSCALE, Kaybase, sparkcognition

APPLICATIONS – INDUSTRY

ADVERTISING
AppNexus, MediaMath, criteo, Xad, Integral Ad Science, rocketfuel, OpenX, MOAT, theTradeDesk, distillery, Algorithmia, drawbridge, LiveIntent, gumgum, TAPAD, DataXu, Yieldmo, Clipper, DYNAMIC YIELD

EDUCATION
KNEWTON, Clever, declara, kidaptive, PANORAMA, knowre, gradescope

GOVERNMENT
Socrata, OPENGOV, mark43, FiscalNote, OpenDataSoft

FINANCE - LENDING
OnDeck, affirm, Kreditech, AVANT, zestfinance, INSIKT, TALA, MoneyLion, TrueAccord, trooly, cignifi, aire, Active.Ai

FINANCE - INVESTING
Dataminr, KENSHO, Quantopian, NUMERAI, iSENTIUM, claritymoney, ALGORIZ, AIDYIA, RavenPack

REAL ESTATE
Opendoor, VTS, CREDiFi, reonomy, COMPSTAK

INSURANCE
metromile, Lemonade, CYENCE, Shift Technology, Tractable

HEALTHCARE
FLATIRON, KYRUUS, HealthTap, METABIOTA, Ginger.io, Glow, DOXIMITY, COTA, zebra, AiCure, enlitic, ovia, imagia, Qventus, ARTERYS, BAYLABS, CLOUD MEDX, IMAGEN, Kang Health, freenome

LIFE SCIENCES
23andMe, color, CarbonX, zymergen, BenevolentAI, PATHWAY GENOMICS, ZEPHYR HEALTH, 3Scan, Clear Labs, Phosphorus, Citrine, twoXAR, Atomwise, deep genomics

TRANSPORTATION
UBER, ZOOX, TESLA, nuTonomy, CLEARPATH, nauto, drive.ai, AUTOMOTIVE, pilot.ai, OPTIMUS RIDE, mobileye, OTTO, nexar, comma.ai, Civil Maps, netradyne, NIO

AGRICULTURE
FARMERS BUSINESS NETWORK, FarmersEdge, FarmLogs, BLUERIVER, mavrx, TerrAvion, prospera

COMMERCE
instacart, STITCH FIX, RetailNext, HowGood

OTHER
eHarmony, stem, rethink robotics, happen, SIGHT MACHINE, BOXEVER, select, VERDIGRIS, duetto, Unbabel, Jukedeck, Second Spectrum

CROSS-INFRASTRUCTURE/ANALYTICS
amazon web services, Google Cloud Platform, Microsoft, IBM, SAP, Hewlett Packard Enterprise, sas, 1010data, vmware, TIBCO, TERADATA, ORACLE, NetApp

OPEN SOURCE

FRAMEWORK
hadoop HDFS, Apache Kylin, hadoop MapReduce, Flink, YARN, TEZ, Spark, MESOS, CDAP

QUERY / DATA FLOW
Spark SQL, presto, HIVE, SLAMDATA, APACHE DRILL, Google Cloud Dataflow

DATA ACCESS
cassandra, nifi, mongoDB, CouchDB, OPENTSDB, riak, HBASE, Spanner, ACCUMULO

COORDINATION
talend, Apache Zookeeper, Apache Ambari

STREAMING
Spark, APEX, Flink, beam, kafka, druid, STORM

STAT TOOLS
python, R, ScalaLab, NumPy, SciPy

AI / MACHINE LEARNING / DEEP LEARNING
TensorFlow, theano, torch, MADlib, learn, Caffe, CNTK, DMTK, Keras, PaddlePaddle, Apache SINGA, OpenAI, mxnet, VELES, WEKA, neon, FeatureFu, Chainer, DIMSUM, DSSTNE, mllib, DL4J, mahout, Aerosolve

SEARCH
elasticsearch, Solr, Lucene

LOG ANALYSIS
elasticsearch, kibana, logstash

VISUALIZATION
BEAKER, Rodeo

COLLABORATION
jupyter, Zeppelin, ANACONDA

SECURITY
Apache Ranger, KNOX, Sentry

DATA SOURCES & APIS

HEALTH
JAWBONE, VALIDIC, practicefusion, fitbit, GARMIN, Human API, kinsa

IOT
GE Digital, UPTAKE, ThingWorx, helium, samsara, AUGURY, estimote

FINANCIAL & ECONOMIC DATA
Bloomberg, THOMSON REUTERS, DOW JONES, S&P CAPITAL IQ, CB INSIGHTS, xignite, quandl, YODLEE, PREMISE, Eagle Alpha, estimize, SECOND MEASURE, YEWNO, StockTwits, PLAID, mattermark, Thinknum

AIR / SPACE / SEA
PLANET LABS, Airware, spire, SKYCATCH, AIRBOTICS, Descartes Labs, UNDERSTORY, TELLUSLABS, WINDWARD, DroneDeploy, MarineTraffic

PEOPLE / ENTITIES
acxiom, Experian, EPSILON, InsideView, Crimson Hexagon, BASIS, quantcast, SAFEGRAPH

LOCATION INTELLIGENCE
FOURSQUARE, MapAnything, Sense360, PlaceIQ, esri, factual, CARTO, Mapillary, STREETLINE

OTHER
qualtrics, DATA.GOV, data.world, panjiva, enigma

DATA RESOURCES

INCUBATORS & SCHOOLS
PLURALSIGHT, GA, galvanize, DataCamp, DataElite, INSIGHT, The Data Incubator, METIS

RESEARCH
facebook research, OpenAI, MIRI, CSAIL, DFKI, CAI, AI2 ALLEN INSTITUTE for ARTIFICIAL INTELLIGENCE

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FIRSTMARK
EARLY STAGE VENTURE CAPITAL

2. Data Models

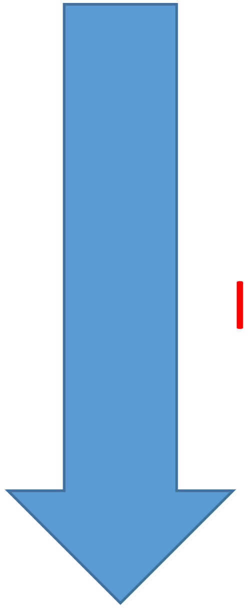
What you will learn about in this section

1. Types of Data

2. Data Models

Data is highly heterogeneous

- Structured data
- Semi-structured data
- Unstructured data



Increasing amounts of data

Structured data

- Information with a high degree of organization
- All data conforms to a schema. Ex: business data
- Easy to query, search over, aggregate
- Example: tables in a database, tables in excel, etc.

Semi-structured data

- Some structure in the data but implicit and irregular
- It contains tags or other markers to separate semantic elements and enforce hierarchies of records and fields within the data
- Example: JSON, HTML, XML

Unstructured data

- Information that either does not have a pre-defined structure or is not organized in a pre-defined manner.

- Text, video, images, etc.

- Abundant and extremely valuable. Hard to query, aggregate, analyze, search.

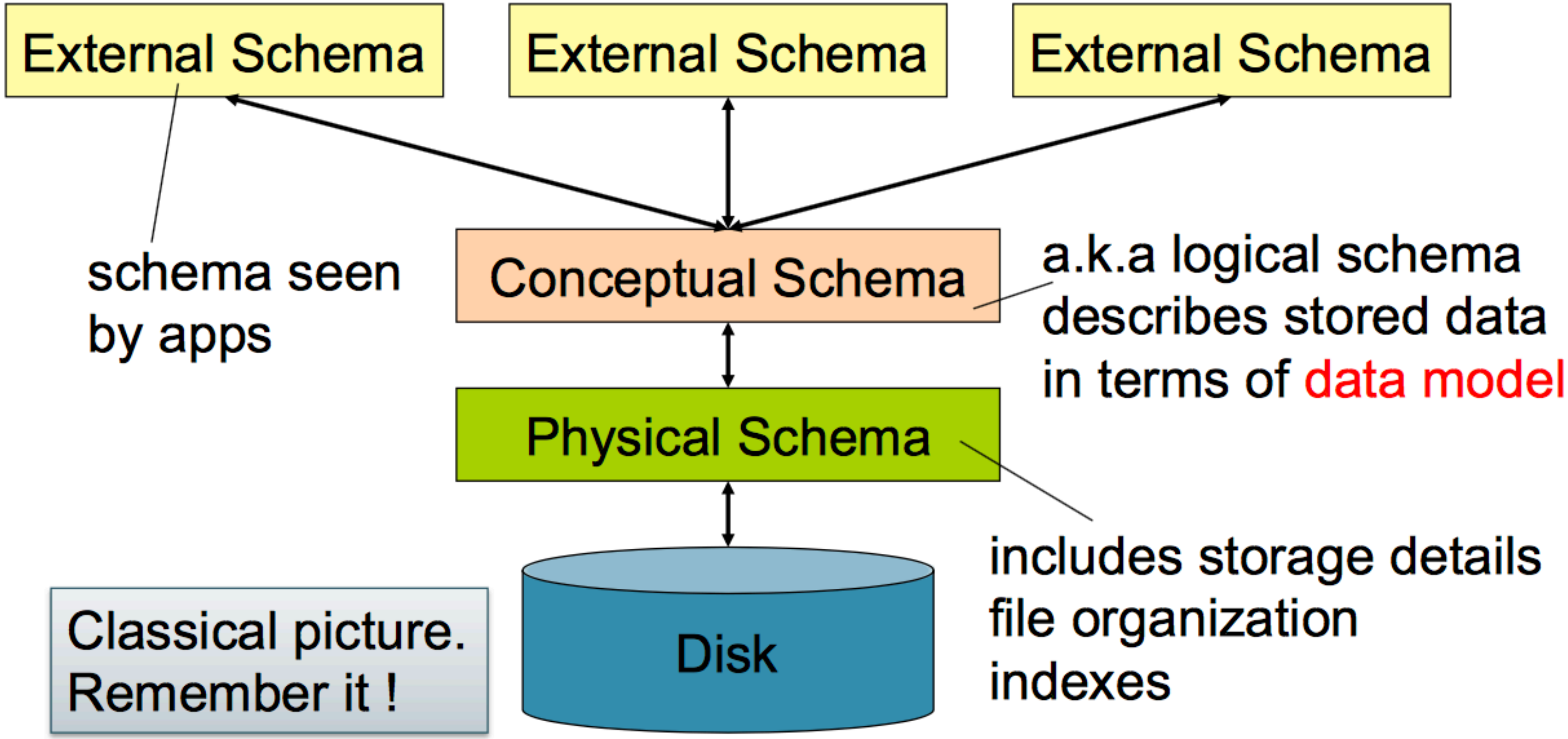
Data Model

- A **data model** is a collection of concepts for describing data

- A **schema** is a description of a particular collection of data, **using the given data model**

- A **data model** enables users to define the data using high-level constructs without worrying about many low-level details of how data will be stored on disk.

Levels of abstraction


External Schema
External Schema
External Schema
schema seen by apps
Conceptual Schema
a.k.a logical schema describes stored data in terms of data model
Physical Schema
includes storage details file organization indexes
Disk
Classical picture. Remember it !

Data models

- Relational
- Key/Value
- Graph
- Document
- Column-family
- Array/Matrix
- Hierarchical
- Network

Most database management systems

Data models

- Relational
- Key/Value
- Graph
- Document
- Column-family
- Array/Matrix
- Hierarchical
- Network

No SQL

Data models

- Relational
- Key/Value
- Graph
- Document
- Column-family
- Array/Matrix

Machine learning, Scientific applications

- Hierarchical
- Network

Data models

- Relational
- Key/Value
- Graph
- Document
- Column-family
- Array/Matrix
- Hierarchical
- Network

Obsolete / Rare

3. RDBMs and the Relational Data Model

What you will learn about in this section

1. Definition of DBMS

2. Data models & the relational data model

3. Schemas & data independence

What is a DBMS?

- A large, integrated collection of data
- Models a real-world *enterprise*
  - *Entities* (e.g., Students, Courses)
  - *Relationships* (e.g., Alice is enrolled in CS564)

A Database Management System (DBMS) is a piece of software designed to store and manage databases

A Motivating, Running Example

- Consider building a course management system (**CMS**):
  - Students
  - Courses
  - Professors

  } *Entities*

  - Who takes what
  - Who teaches what

  } *Relationships*

Data models

- A **data model** is a collection of concepts for describing data
  - The relational model of data is the most widely used model today
    - Main Concept: the *relation*- essentially, a table

- A **schema** is a description of a particular collection of data, **using the given data model**
  - E.g. every *relation* in a relational data model has a *schema* describing types, etc.

Modeling the Course Management System

- *Logical Schema*
  - Students(sid: *string*, name: *string*, gpa: *float*)
  - Courses(cid: *string*, cname: *string*, credits: *int*)
  - Enrolled(sid: *string,* cid*: string,* grade*: string*)

sid	Name	Gpa
101	Bob	3.2
123	Mary	3.8

Students

Relations

cid	cname	credits
564	564-2	4
308	417	2

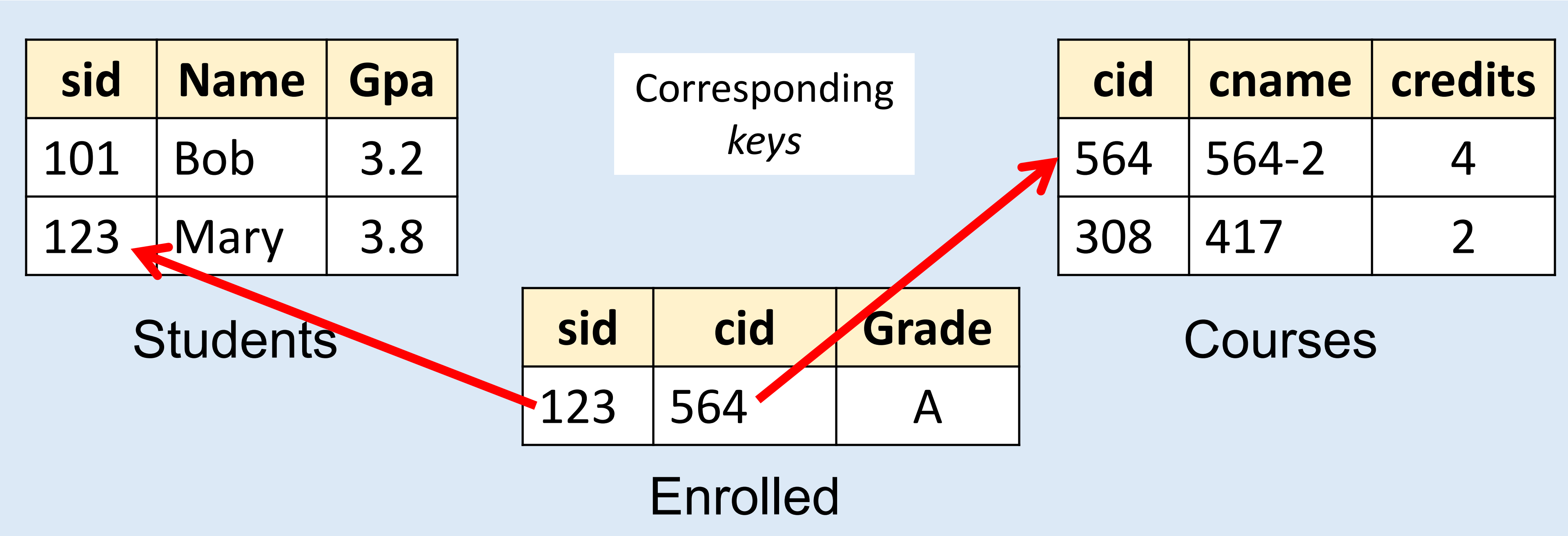
Courses

sid	cid	Grade
123	564	A

Enrolled

Modeling the Course Management System

- *Logical Schema*
  - Students(sid: *string*, name: *string*, gpa: *float*)
  - Courses(cid: *string*, cname: *string*, credits: *int*)
  - Enrolled(sid: *string,* cid*: string,* grade*: string*)



sid	Name	Gpa
101	Bob	3.2
123	Mary	3.8

Students

Corresponding *keys*

cid	cname	credits
564	564-2	4
308	417	2

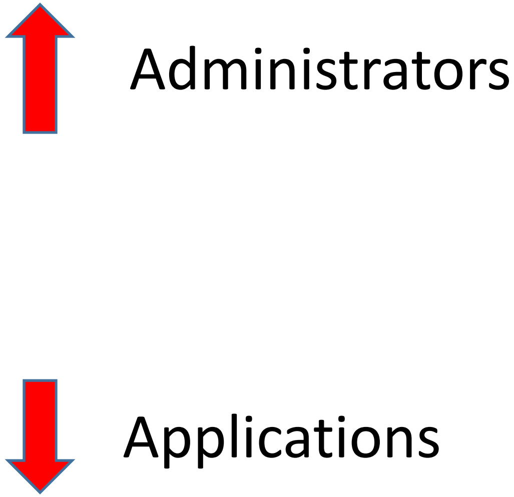
Courses

sid	cid	Grade
123	564	A

Enrolled

Other Schemata…

- *Physical Schema*: describes data layout
  - Relations as unordered files
  - Some data in sorted order (index)
- *Logical Schema:* Previous slide
- *External Schema*: (Views)
  - Course_info(cid: *string*, enrollment: *integer*)
  - Derived from other tables



Administrators

Applications

Data independence

Concept: Applications do not need to worry about *how the data is structured and stored*

Logical data independence: protection from changes in the *logical structure of the data*

I.e. should not need to ask: can we add a new entity or attribute without rewriting the application?

Physical data independence: protection from *physical layout changes*

I.e. should not need to ask: which disks are the data stored on? Is the data indexed?

One of the most important reasons to use a DBMS

Relational Model

- **Structure:** The definition of relations and their contents.
- **Integrity:** Ensure the database's contents satisfy constraints.
- **Manipulation:** How to access and modify a database's contents.

Tables in the Relational Model

Product

PName	Price	Manufacturer
Gizmo	$19.99	GizmoWorks
Powergizmo	$29.99	GizmoWorks
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

A **relation** or **table** is a multiset of tuples having the attributes specified by the schema

Let’s break this definition down

Tables in the Relational Model

Product

PName	Price	Manufacturer
Gizmo	$19.99	GizmoWorks
Powergizmo	$29.99	GizmoWorks
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

A **multiset** is an unordered list (or: a set with multiple duplicate instances allowed)

List:	[1, 1, 2, 3]
Set:	{1, 2, 3}
Multiset:	{1, 1, 2, 3}

i.e. no *next()*, etc. methods!

Tables in the Relational Model

Product

PName	Price	Manufacturer
Gizmo	$19.99	GizmoWorks
Powergizmo	$29.99	GizmoWorks
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

An **attribute** (or **column**) is a typed data entry present in each tuple in the relation

Attributes must have an ***atomic*** *type, i.e. not a list, set, etc.*

Tables in the Relational Model

Product

PName	Price	Manufacturer
Gizmo	$19.99	GizmoWorks
Powergizmo	$29.99	GizmoWorks
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

*Also referred to sometimes as a **record***

A **tuple** or **row** is a single entry in the table having the attributes specified by the schema

Tables in the Relational Model

Product

PName	Price	Manufacturer
Gizmo	$19.99	GizmoWorks
Powergizmo	$29.99	GizmoWorks
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

The number of tuples is the <u>cardinality</u> of the relation

The number of attributes is the <u>arity</u> of the relation

***n*-ary Relation**

=

Table with *n* columns

Data Types in Relational Model

- Atomic types:
  - Characters: CHAR(20), VARCHAR(50)
  - Numbers: INT, BIGINT, SMALLINT, FLOAT
  - Others: MONEY, DATETIME, …

- Every attribute must have an atomic type
  - Hence tables are flat

Table Schemas

- The **schema** of a table is the table name, its attributes, and their types:

```
Product(Pname: string, Price: float, Category:
string, Manufacturer: string)
```

- A **key** is an attribute whose values are unique; we underline a key

```
Product(Pname: string, Price: float, Category:
string, Manufacturer: string)
```

Key constraints

A key is a **minimal subset of attributes** that acts as a unique identifier for tuples in a relation

- A key is an implicit constraint on which tuples can be in the relation
  - i.e. if two tuples agree on the values of the key, then they must be the same tuple!

```
Students(sid:string, name:string, gpa: float)
```

1. Which would you select as a key?
2. Is a key always guaranteed to exist?
3. Can we have more than one key?

NULL and NOT NULL

- To say "don't know the value" we use NULL
  - NULL has (sometimes painful) semantics, more details later

```
Students(sid:string, name:string, gpa: float)
```

sid	name	gpa
123	Bob	3.9
143	Jim	NULL

Say, Jim just enrolled in his first class.

We may constrain a column to be NOT NULL, e.g., "name" in this table

Foreign Key constraints

- A foreign key specifies that an attribute from one relation has to map to a tuple in another relation.

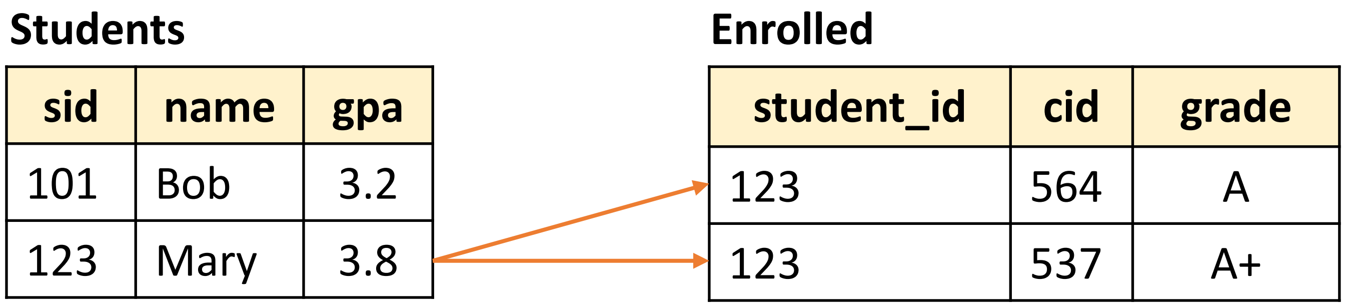
Foreign Key constraints

- Suppose we have the following schema:

Students(sid: *string*, name: *string*, gpa: *float*)

Enrolled(student_id: *string*, cid: *string*, grade: *string*)

- And we want to impose the following constraint:
  - ‘Only real students may enroll in courses’ i.e. a student must appear in the Students table to enroll in a class



Students

sid	name	gpa
101	Bob	3.2
123	Mary	3.8

Enrolled

student_id	cid	grade
123	564	A
123	537	A+

student_id alone is not a key- what is?

We say that student_id is a **foreign key** that refers to Students

Summary of Schema Information

- Schema and Constraints are how databases understand the semantics (meaning) of data

- They are also useful for optimization

DATA MANIPULATION LANGUAGES (DML)

- How to store and retrieve information from a database.

- Procedural: The query specifies the (high-level) strategy the DBMS should use to find the desired result.

- We will see SQL and Relational Algebra