The Long Pause to Regroup

The transition from Antiquity to the Renaissance, with influences from the Near East

Rome

- Italian peninsula occupied by 1000 BCE by Latin speaking tribes
  - 800 BCE:
    - Greeks arrive in south
    - Etruscans in north
  - Rome became a republic in 509 BCE
    - Power invested in a Senate

Roman Technology

- Romans were great engineers
- Roads, aqueducts, buildings, cities
- The Rule of Law
  - The authority of Roman government was based upon written laws enacted by its senate.

A surviving Roman aqueduct at Nîmes in France.
Roman Science

- "Greek science written in Latin"
- Transmitted to Rome in the Hellenistic period (300 BCE - 200 CE)
  - Mostly via the Museum in Alexandria and those trained there.

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Biological Science

- Herophilus of Alexandria (250 BCE?)
  - Dissection of live human bodies
- Galen (b. 129 CE)
  - Worked in Roman Empire
  - Sought principles of medicine
  - Wrote definitive treatise on anatomy and physiology
  - Became the standard text for over 1400 years

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Roman Mathematics

- Very difficult to find anything novel.
- Calculation in the Roman Empire was hampered by the system of Roman numerals:

<table>
<thead>
<tr>
<th>1-10</th>
<th>10-19</th>
<th>20-99</th>
<th>100-900</th>
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<tbody>
<tr>
<td>I=1</td>
<td>III=3</td>
<td>VIII=9</td>
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<td>II=2</td>
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<td>V=5</td>
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<td>VII=7</td>
<td>VIII=8</td>
<td>IX=9</td>
<td>M=1000</td>
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Calculation in the Roman Empire was hampered by the system of Roman numerals.
Imagine the difficulty of arithmetic operations

- Compare 3629 x 2983
- To MMMDCXXIX x MMCMLXXXIII

Note:
- Like the Egyptians, the Romans used a decimal-based system and had separate symbols for the units, tens, hundreds, thousands, millions, etc.
- Like the Babylonians, the Romans had place value in that the larger numerals were always to the left of lesser numerals, with the exception of the special symbols for the 4 and 9 position: IV and IX, XL and XC, CD and CM, etc.

Romans were practical

- The only interest that Romans took in mathematics was what was necessary for commerce and engineering.
- They had no interest in, say, geometry for its own sake. Theoretical knowledge was little valued.

Roman engineering

- Roman engineering was amazing for its time. But it required relatively little mathematics. Roman engineers learned only what they deemed necessary to know.
- The famous engineer-architect Argippa, who undertook a survey of the entire Roman empire, had to call in specialists from Alexandria to carry out the measurements and calculations.
The Julian Calendar

- Introduced 45 BCE, by Julius Caesar
- 365-day year with leap years every fourth year
- Much better than all previous calendars
- Recognition that the year is not evenly divided into days.

Encyclopaedists

- In the late Roman Empire.
- Attempted to write down “everything” they knew in “Epitomes.”
- Often totally disorganized, but great source for historians to figure out what people knew and believed.

Martianus Capella

- An exception: Martianus Capella’s organization of knowledge into the 7 Liberal Arts
  - Trivium
    - Grammar, Dialectic, Rhetoric
  - Quadrivium
    - Geometry, Arithmetic, Astronomy, Music
The Roman Empire at its height

Byzantium

- In 395 C.E., the Roman Empire was divided into an Eastern and a Western branch.
- The Eastern Empire, “Byzantium,” based in Constantinople, thrived, lasting until 1453.
  - Largely Greek influence

Emperor Justinian 527-565

- Emperor of the Eastern Roman Empire
  - Called later the “Byzantine Empire”
- Justinian tried to re-unite the Eastern and Western empires, unsuccessfully
  - Tried to establish Latin across his empire.
  - After his death, Greek became the official language.
The Corpus Juris

- Justinian commissioned a summary of Roman Law.
- Part of his effort to re-unite the empire.
- Was completed by a team of scholars in only eight years, but was a fraction of the body of law.
- Centuries later, in the west, the Corpus Juris was taken to be the final and perfect expression of Roman Law.

The Byzantine Empire

- Successfully defended itself from attack from North, East, and West when other cultures fell.
- Superior knowledge of military technologies, not involving guns.
- Finally fell to the Ottoman Turks in 1453
- Famous victory for guns.
- One of the traditional dates for the end of the Middle Ages and the beginning of the Modern Era.

Greek Fire

- A Byzantine terror weapon.
- A petroleum based liquid.
- Caught fire when it hit the water. It was a mainstay of Byzantine defence from both Arabs and Slavs from as early as the 7th century.
The Decline of the (Western) Roman Empire

- The Roman Empire had spread across Europe, North Africa, and the Near East during the thousand years from 500 BCE to 500 CE.
- The western empire then collapsed, leaving a governmental void across much of Western civilization.

The Fall of Rome

- Many reasons are given for the fall of the Roman Empire.
- Possibly they were no longer able to feed themselves by importing food from their colonies.

Ruins of Leptis Magna (now in Libya). A great city in a region that supplied food to Rome. Overfarming made the land unproductive. It is now a desert.

Europe in the Dark Ages

- The period between antiquity (ancient times), marked by the fall of Rome around 500 C.E., and the beginning of the modern era (around the middle of the 15th century) is called the Medieval period, or the Middle Ages.
- The first 500 years of that is called the Dark Ages (about 500-1000 C.E.).
- During this time Europe was overrun by nomadic tribes from the north and west.
- Literacy was lost, farming techniques forgotten, infrastructure deteriorated.
- Villages became isolated from each other.
Charlemagne
- Europe began to recover under Charles the Great (Charlemagne).
- In 800 he was crowned Holy Roman Emperor.
- He saw illiteracy as one of the major problems facing Europe.

Schools
- Charlemagne founded schools in cathedrals all over Europe.
  - The language of instruction was Latin.
  - The curriculum was the seven liberal arts, using Martianus Capella's work.
- When Charlemagne died many of his reforms were lost, but some of the schools remained and became the bases of later European universities.

The Recovery of Europe
- By the early 1400s, Europe had pulled itself out of its disorganization after the fall of Rome.
- The feudal system provided stable government and protection from raiders.
- The economy was flourishing and the population rising and in good health.
- But there was little literacy and almost no knowledge of ancient science.
The Rise of Islam

- Before Mohammed
  - Arab culture disorganized
    - nomadic, polytheistic
    - centered in Mecca
- Mohammed
  - born 570 in Mecca
  - at age of 40 had revelation, became prophet and fled Mecca in 622 (traditional date for start of Islam)
- Mohammed's revelations = the Koran (Qu'ran)
  - One God, one Prophet, one Book

The Spread of Islam

- In 100 years (630-730) Islam spread from Arabia to India in the East and to Spain in the West.

The founding of Baghdad

- In 762, the rulers of the Islamic empire, the caliphs (i.e., “successors”), then in Damascus, decided to found a new capital on the Tigris river at the site of a small town known by the Persian name, Baghdad.
- By the ninth century, Baghdad had a population of 800,000, making it larger than Constantinople.
The rise of Arabic

- Arabic became the language of learning.
- All Moslems had to learn Arabic to read the Koran.
- Anything written in Arabic carried the prestige previously reserved for works in Greek.

The House of Wisdom

- Caliph al-Ma’mûn established a great academy, the House of Wisdom, in Baghdad, comparable to the Museum in Alexandria.
- The House of Wisdom set out to acquire all the great Greek manuscripts and works of other cultures.
- An emissary was sent to Constantinople to obtain a copy of Euclid’s *Elements* from the Byzantine Emperor.

The House of Wisdom, 2

- By the beginning of the tenth century, almost all the available Greek scientific and philosophical works had been translated into Arabic at the House of Wisdom.
- Copies of these and other works were then made and sent to Islamic libraries throughout Islam.
- Islamic scholars then began to extend and refine all these works, creating a huge body of scholarship.
Arab mathematics

- One of the greatest Arab mathematicians whose work was preserved in these libraries was Mohammed ibn Musa al-Khowârizimi, who lived approximately from 780 to 850. His patron was Caliph al Ma'mûn.
- He was the court astronomer to the Caliph and one of the early scholars at the House of Wisdom.

Al-Khowârizimi’s works

- Al-Khowârizimi wrote two works that became enormously influential in both the Islamic world and later in Europe when they were translated into Latin.
- One was on arithmetic, the other on algebra.

Al-Khowârizimi’s Arithmetic

- Al-Khowârizimi’s book on arithmetic had a title that could be translated as *Book of Addition and Subtraction According to the Hindu Calculation*.
- It explained the Hindu method of writing numerals and the decimal system.
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0

- Al-Khowârizimi mentions “nine letters” meaning the symbols for the numerals 1 to 9.
- He also introduces the symbol and use of the place holder, zero:
  - “When nothing remains [in subtraction], put down a small circle so that the place be not empty, but the circle must occupy it.”

The influence of al-Khowârizimi’s arithmetic text

- All copies of al-Khowârizimi’s original Arabic text have been lost.
- We have only a Latin translation, *Algoritmi de numero Indorum* by John Seville from the early 12th century.
- So great was its influence that the new numerals were misnamed “Arabic” because of al-Khowârizimi’s book, despite being referred to there as of Indian origin.

Al-Khowârizimi’s algebra text

- Though the *Arithmetica* of Diophantus, a Greek, was written long before al-Khowârizimi’s and, despite the name, was really about algebra, Western Europe first learned about algebra from al-Khowârizimi’s book.
  - Diophantus’s work was not translated into Latin until long after al-Khowârizimi’s.
  - Did al-Khowârizimi learn algebra from Diophantus’s Greek text?
    - Unlikely, since their approaches are entirely different.
Al-jabr

- The title of al-Khowârizimi’s algebra text, in transliterated Arabic, is *Hisâb al-jabr w'al muqâbalah*, which means something like “the science of reunion and reduction.
- Reunion meaning transferring negative terms to the other side of the equation.
- Reduction meaning combining like terms on the same side into a single term, or cancelling like terms on both sides.

Algebra

- The title, *Hisâb al-jabr w'al muqâbalah*, was translated into Latin as *Liber Algebrae et Almucabola*, from which we have taken “algebra” as the mathematics of solving equations for unknowns.
- Likewise our work “algorithm”, meaning a specified procedure to follow to solve a problem is merely a Latinized version of al-Khowârizimi’s name.

Al-Khowârizimi the transmitter, not the inventor

- Just as Euclid’s work was the means by which much of Greek mathematics became known to a wider world, al-Khowârizimi’s books were the vehicles for the transmission of the old Persian mathematical knowledge to the rest of the world.
Algebra as divine revelation

- Algebraic formulae and algorithms were expressed as rhetorical pronouncements, in verse, or as aphorisms. No symbols were used. No proofs were supplied.
- Any demonstrations given as justification were usually in a geometric form, inspired by Euclid.
- Perhaps it was felt that an argument had to be geometric to convince.

A geometric solution

- Consider a problem that we would write as $x^2 + 10x = 39$.
- The central square is $x^2$.
- The four rectangles equal $10x$.
- The four small squares at the edges have area $4\left(\frac{10}{4}\right)^2 = 100/4 = 25$.
- Therefore the entire large square is equal to $x^2 + 10x + 25$.
- Since $x^2 + 10x + 25 = 39 + 25 = 64$.
- Therefore the side of the large square is $\sqrt{64} = 8$.
- Therefore $x = 8 - 10/2 = 3$.
- This is the method called completing the square.

The Crusades

- The Byzantine Empire, feeling threatened by the encroaching Islamic Caliphate, appealed to Christian Europe for military assistance.
- Thus began the Crusades to free the Holy Land, starting in 1092, and lasting about 300 years.
The Surprise Discovery

- Much to the surprise of the invading Christians, the Muslim world was much more literate and culturally advanced than Europe.
- Europeans discovered a wealth of literature, much of it originally written in Greek, that was unknown in medieval Europe.
  - Among these were works of Euclid, Ptolemy, and much of Aristotle.

Greek texts in Arabic

- Euclid’s *Elements* was available in Arabic by the year 800.
- Ptolemy’s *Megale Syntaxis* (“Great Composition”) appeared in Arabic in 827, where the title was transliterated as “Al Magest”
  - The Arabic title stuck when it was translated into Latin later. We know it in English as *The Almagest*.

The Great Translation Project

- A huge project was undertaken to translate much of this literature from Arabic into Latin to be accessible to European scholars.
  - At Toledo, Spain, over 150 years.
  - The typical process:
    - Jewish rabbis, fluent in Arabic and Spanish, translated into Spanish.
- The translated works were sent to Italy and became the foundation for scholarship at the new European universities.
Scholasticism

- The European universities tried to digest the new learning in a Christian context.
- Aristotle’s world view was taken as a base for Christian dogma, and all scientific understanding was fit to that context, including Ptolemy’s *Almagest*, which therefore became theologically correct.

The Black Death

- Bubonic plague hit Europe in 1346.
- The Black Death eliminated 1/3 to 1/2 of population of Europe.

The Black Death as Retribution

- This illness was called the Black Death because sores, skin, blood, vomit, etc., all turned black before the patient died, often within a few hours of becoming ill.
- At the time it was widely thought to be divine retribution for sinful living. It was worst in port cities.
A New Beginning for Europe

- After the Black Death, the economy of Europe took off.
- Fewer people sharing the same resources.
- Emphasis on labour-saving devices.
- The Renaissance began in earnest.

The Demand for Books

- When the Renaissance got underway, more and more people in Europe wanted access to the mass of written scholarship that was accumulating from the translations of Moslem works from Arabic and of Byzantine works from Greek.

The Demand for Books, 2

- Paper from Linen was readily available.
- But scribes were in great demand and could not keep up.
Printed Block Books

- A means of printing any written material mechanically would be in demand.
- Mechanical printing was known in China for at least 1000 years.
- But the method required making a woodcut of an entire page (in mirror image), then inking the woodcut, then applying it to a piece of paper.

Printing from Movable Type

- Some “block books” were printed in Europe in the 15th century.
- But the process was cumbersome, and error-prone.
  - A single mistake on one page required that the entire page be re-carved.
  - A method was needed to assemble a page, letter by letter.

Gutenberg’s Printing Press

- Johann Gutenberg (1400-1468).
  - Goldsmith from Mainz, Germany.
  - Found a method of manufacturing individual letter slugs (that print the letter) of a uniform height so they could be lined up on a bed, inked, and a sheet of paper pressed against them to print a page.
Gutenberg’s matrix

- Gutenberg’s trick was to use the same mould for all letter slugs, but placing a different letter impression on the end to make different letters.
- A molten lead alloy is poured into a matrix with the letter impression on the end, held together with a firm spring.
- The matrix adjusts to the width of the letters desired.
- Wide for “M”, narrow for “I”, etc.

The Bed of the Press

- The desired letters for a page are then arranged and lined up on a flat bed, secured in place and inked.
- A sheet of paper is loaded into a frame held above the bed and then pressed onto the inked letters with a forceful screw press.

The finished product

- The printed page can contain any text whatsoever that can be written in Latin letters.
- When sufficient copies are made, the letter slugs are removed and sorted ready for another page to be composed.
Printing was immensely successful. In the 50 years from 1450 to 1500 more than 10 million volumes were printed.

Printing changed the world

The character of education, general knowledge, the dissemination of information, and all the infrastructure of civilization changed dramatically with the invention of printing.

Influence of Printing on Science

More texts available, to a wider audience.
Publishing scientific discoveries became the norm.
Interest in new knowledge (e.g., from exploration).
The woodcut

- Soon after the invention of printing with movable type, the woodcut was invented, providing a method of printing illustrations in a book.
- This was of major benefit to biology, where illustrations of animals and plants could be compared to the real things.
- Especially the “Herbals,” pharmaceutical texts on preparing medicines from wild growing herbs.
- The illustration here is from Otto Brunfels’s Living Portraits of Plants, 1530.

Comparative anatomy diagrams

- Illustrations, side-by-side, of the skeletons of different animals (here a human and a bird) showed relationships that would not have occurred to the ordinary observer.

Renaissance Illustrations of Previously “Unknown” Animals

- A creature resembling a bull, but larger. And, a scaly “fish man.”
The Revival of Learning

- Started with the 12th century translation project.
- Translated works formed basis of curriculum at medieval universities.
- In the 15th century Byzantine manuscripts were imported into Western Europe.

Humanism

- Replaced theology in status.
- Relations of people in society.
- Activity: reworking Classical literature.
- Rebellion against Scholasticism.
- Worshipped remote past.

Early Humanism

- Manuel Chrysoloras came to Italy in 1397 from Byzantium.
- Taught Greek in Italy.
- Sources dried up after 1453.
Printing of Ancient Scientific Classics

- Early printing was of very old texts:
  - Bible, theology, law, medicine
  - Few contemporary works
  - Few scientific works
- Need for Latin translations:
  - Very few Western Europeans literate in Greek even into the 16th and 17th centuries.
  - Greek science had to be translated into Latin.
- Among the first to be translated:
  - Euclid
  - Medical works: Hippocrates, Dioscorides, Galen, etc.

Scientific Atmosphere in Early Renaissance

- Little interest in science among humanists
- Had to wait for translations from Greek
- Scholasticism gave way to Empiricism
- Closer study of nature became the norm.

The Founding of the Universities

- The original *universitas* was merely a collection of individuals who came together to communicate ideas.
- The original *universitas* were located at the monastery and cathedral schools founded by Charlemagne, and their purpose was to prepare students for the priesthood.
- Their function was to preserve, not advance, knowledge.
- The reputation of a particular school depended largely on the reputation of its teachers. Teachers were paid directly by the students. A famous teacher attracted large numbers of students and enriched the town where the school was located.
Student organization

- Students banded together to protect themselves from extortion by local citizens and to secure legal rights. These associations formed the administrative structure of the emerging universities.
- Eventually they gained legal recognition through a charter from the king or the pope.
- All the early medieval universities were formed this way: Bologna (1158), Paris (1200), Padua (1222), Oxford (1214), and Cambridge (1231).

The Seven Liberal Arts

- As at Charlemagne's cathedral schools, the curriculum at the new universities followed the seven liberal arts of Martianus Capella:
  - The Trivium
    - Grammar, Dialectic, Rhetoric
  - The Quadrivium
    - Geometry, Arithmetic, Astronomy, Music
- This would suggest that mathematics was given a high place of importance, but in fact, little attention was given to the Quadrivium on the grounds that those subjects were "practical" and a university education was held to be "general."

Perspective in Maps

- Paolo Toscanelli (1396-1482)
  - Brought Ptolemy's Geography to Italy
Engineering marvels

- Filippo Brunelleschi (1377-1446)
  - Renaissance Man
  - Built Dome of cathedral in Florence.

Perspective in Architecture

- Brunelleschi built churches with perspective tricks to make them grander
  - The Church of San Lorenzo in Florence looks longer than it is.
  - Popularised perspective in art and architecture.

Perspective in art

- Leone Battista Alberti (1404-1472)
  - Discovered mathematical laws of perspective.
- Albrecht Dürer of Nuremberg (1471-1528)
  - Used Alberti's analysis to portray the proportions of human body accurately by age and sex.
Leonardo da Vinci

- 1452-1519
- Genius in some areas, barely functioning in others
  - Small artistic output
  - Intense working style and attention to detail
  - Very secretive

Scientific interests:
- Flying machine
- Helicopter
- Parachute
- Designed parabolic compass
- Designed guns, other engineering apparatus

Leonardo da Vinci’s Parabola Compass

- Designed parabolic compass. The pencil $AB$ moves on a fixed center with the pencil $CD$. A fixed body through lines $AC$ and $CD$ as a right arm. If a small, very light proof is moved from a stick on a horizontal center, the lower making is moved by the center on the upper arm. The stick is turned by $BC$ to a line.
Leonardo da Vinci
- Perspective and realism in art
  - Worked out principles of perspective
  - Studied physiology, embryology

Practical Arts in the 16th century
- Greatly advanced by the printing of technical manuals.

Practical Arts in the 16th century
- Waterwheel operating mechanical bellows for a blast furnace.
  - From Vanocchio Biringuccio (1460-1539), Pirotechnia (1540).
Practical Arts in the 16th century

- Agricola (1490-1555)
  - (George Bauer)
  - De Re Metallica (1556)

Medicine

- Medicine followed the teachings and practices of the ancient authorities, Hippocrates, Galen, Avicenna.
- Renaissance physicians began to throw off blind adherence to authority in favour of direct observation and new theories.

An anatomy lesson

- An anatomy demonstration from the 15th century.
- The professor reads from the text, while the demonstrator (surgeon) displays the appropriate organs.

Anatomy lesson from Mondino's Anathomia, 1493
Paracelsus

- 1493-1541
- Actual name: Aureolus Philleppus Theophrastus Bombastus von Hohenheim
- Founded Iatrochemistry, i.e. medical chemistry
  - Curing diseases with specific drugs, instead of curing the body as a whole.

Andreas Vesalius

- 1514-1564
- Studied anatomy (i.e., Galen) in Paris, 1533-1536
- In 1537 began teaching surgery in Padua.
- Vesalius emphasized actual demonstrations of anatomy in the (new) anatomy theatre in Padua.

De Fabrica

- Published *On the Fabric of the Human Body*, in 1543.
  - Note: This is the same year as that in which Copernicus published *On the Revolutions of the Heavenly Spheres*.
- An illustrated anatomy text.
  - Raised biological observations to new level.
  - Artist for book probably from school of Titian.