How is DNA used to solve crimes?
Criminal cases are built on three types of evidence:

- **Identification evidence** – a witness coming into the court and saying, “That’s him, that’s the man.”

- **Physical evidence** – the victim’s property or a weapon found in the defendant’s pocket.

- **Confessions** – admissions from the defendant’s own mouth
Juries convict when all three kinds of evidence are present and when each kind corroborates the others.
When there is only one kind of evidence, a jury **may** convict or they **may not**, depending on the weight and quality of the single leg of the triad of criminal proof.
The Advent of DNA Evidence:

– DNA evidence technically doesn't pinpoint a single suspect, but rather narrows it down to just a few possibilities within the human population. However, it's extremely accurate and useful as long as it is handled and analyzed properly.

– DNA exists in the cells of all living organisms.

– Only one-tenth of 1 percent of human DNA differs from one individual to the next. Although estimates vary, studies suggest that forensic DNA analysis is roughly 95 percent accurate.
DNA profiling didn't exist until the mid-1980s, when an English scientist, Dr. Alec Jeffreys, discovered that certain areas of the DNA strand contain patterns that repeat many times. VNTR = Variable Number Tandem Repeats.

The number of these repetitions varies between individuals, and Dr. Jeffreys developed a test to measure the variation in length of these repetitions.

Using this test, Dr. Jeffreys found that he was able to identify individuals by comparing samples of their DNA. This test became known as RFLP = Restriction Fragment Length Polymorphism.

RFLP is an accurate and reliable test, but it requires a relatively large amount of DNA to work with. Laboratories can now use tests based on the Polymerase Chain Reaction (PCR) method, which allows for testing on very small amounts of DNA from biological samples.
Eukaryotic Genes:

- Contain sections that code for a trait, mixed with sections that do not. These non-coding sections are called **Introns**:
  - 80 -10,000 nucleotides long.
  - Contain VNTRs, which make the introns found in some people’s DNA longer or shorter than those found in the same position in another person’s DNA.

- **Exons** are the coding sequences.
  - Are the same size, in the same position from person to person.
How DNA is Sourced & Analyzed

- Investigators can collect DNA evidence from any biological evidence found at a crime scene, although not every sample contains sufficient amounts of DNA to enable DNA profiling.

- If investigators already have suspect(s) in mind, they can collect samples to compare to the evidence collected at the scene. There are also a database of DNA profiles called CODIS (Combined DNA Index System) that investigators can use to identify suspects by comparing the database information to the DNA profile obtained from evidence.

The list that follows identifies some common items of evidence that you may need to collect, the possible location of the DNA on the evidence, and the biological source containing the cells.
<table>
<thead>
<tr>
<th>Evidence</th>
<th>Possible Location of DNA on the Evidence</th>
<th>Source of DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball bat or similar weapon</td>
<td>handle, end</td>
<td>sweat, skin, blood, tissue</td>
</tr>
<tr>
<td>Hat, bandanna, or mask</td>
<td>inside</td>
<td>sweat, hair, dandruff</td>
</tr>
<tr>
<td>Eyeglasses</td>
<td>nose or ear pieces, lens</td>
<td>sweat, skin</td>
</tr>
<tr>
<td>Facial tissue, cotton swab</td>
<td>surface area</td>
<td>mucus, blood, sweat, semen, ear wax</td>
</tr>
<tr>
<td>Dirty laundry</td>
<td>surface area</td>
<td>blood, sweat, semen</td>
</tr>
<tr>
<td>Toothpick</td>
<td>tips</td>
<td>saliva</td>
</tr>
<tr>
<td>Used cigarette</td>
<td>cigarette butt</td>
<td>saliva</td>
</tr>
<tr>
<td>Stamp or envelope</td>
<td>licked area</td>
<td>saliva</td>
</tr>
<tr>
<td>Tape or ligature</td>
<td>inside/outside surface</td>
<td>skin, sweat</td>
</tr>
<tr>
<td>Bottle, can, or glass</td>
<td>sides, mouthpiece</td>
<td>saliva, sweat</td>
</tr>
<tr>
<td>Used condom</td>
<td>inside/outside surface</td>
<td>semen, vaginal, rectal cells</td>
</tr>
<tr>
<td>Blanket, pillow, sheet</td>
<td>surface area</td>
<td>sweat, hair, semen, urine, saliva</td>
</tr>
<tr>
<td>“Through and through&quot; bullet</td>
<td>outside surface</td>
<td>blood, tissue</td>
</tr>
<tr>
<td>Bite mark</td>
<td>person's skin or clothing</td>
<td>saliva</td>
</tr>
<tr>
<td>Fingernail</td>
<td>scrapings</td>
<td>blood, sweat, tissue</td>
</tr>
</tbody>
</table>
Contamination & Storage

– The risk of contamination of any crime scene can be reduced by limiting incidental activity (refrain from smoking, eating, drinking, littering, etc).

– **Chain of Custody**

  – Documentation is critical to maintaining the integrity of the chain of custody. If laboratory analysis reveals that DNA evidence was contaminated, it may be necessary to identify persons who have handled that evidence.

  – In processing the evidence, the fewer people handling the evidence, the better.

– **Transportation and Storage**

  – Direct sunlight and warmer conditions may degrade DNA, store it in a cold environment.

  – Any probative biological sample that has been stored dry or frozen, regardless of age, may be considered for DNA analysis. Nuclear DNA from blood and semen stains more than 20 years old has been analyzed successfully using polymerase chain reaction (PCR).

  – Samples generally considered unsuitable for testing with current techniques include:

    – embalmed bodies;
    – pathology or fetal tissue immersed in formaldehyde or formalin for more than a few hours;
    – urine stains.
How is DNA fingerprint produced using RFLP?

– Step #1 - Extract DNA from a sample of human material, usually blood.

– Step #2 - Restriction enzymes are used to cut the DNA. This results in thousands of pieces of DNA with a variety of different lengths.

– What is a restriction enzyme, and how does it work?
  – Restriction enzymes cut a DNA molecule at a particular place.
  – They "scan" a DNA molecule, looking for a particular base sequence, usually of four to six nucleotides.
  – Once it finds this recognition sequence, it stops and cuts the strands.
  – The recognition sequence is on both strands, but runs in opposite directions. This allows the enzyme to cut both strands.
Restriction Enzymes

- Evolved in bacteria to protect against them from viral DNA infection.
- There are over 3,000 different restriction enzymes known.
- Each one searches a DNA strand for a specific sequence of bases when they cut the DNA.
- The sequence is different for each enzyme.
When restriction enzymes cut, they produce two different types of ends on the DNA molecule:

- **Sticky Ends:** have a short segment of single stranded DNA on each end of the fragments produced.

- **Blunt Ends:** have no single strands on their ends after they are cut.
<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Recognition Sequence&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Microorganism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alul</td>
<td>AG↓C*T</td>
<td>Arthrobacter luteus</td>
</tr>
<tr>
<td>BamHI</td>
<td>G↓GATC*C</td>
<td>Bacillus amylooliquefaciens H</td>
</tr>
<tr>
<td>BglII</td>
<td>GCCNNNNNN↓NGGC</td>
<td>Bacillus globigii</td>
</tr>
<tr>
<td>BglIII</td>
<td>A↓GATCT</td>
<td>Bacillus globigii</td>
</tr>
<tr>
<td>EcoRI</td>
<td>G↓AA*TTC</td>
<td>Escherichia coli RY13</td>
</tr>
<tr>
<td>EcoRII</td>
<td>↓CC* (A)GG</td>
<td>Escherichia coli R245</td>
</tr>
<tr>
<td>EcoRV</td>
<td>GA*T↓ATC</td>
<td>Escherichia coli J62P4G74</td>
</tr>
<tr>
<td>HaeII</td>
<td>RGCGC↓Y</td>
<td>Haemophilus aegyptius</td>
</tr>
<tr>
<td>HaeIII</td>
<td>GG↓C*C</td>
<td>Haemophilus aegyptius</td>
</tr>
<tr>
<td>HindIII</td>
<td>A*↓AGCTT</td>
<td>Haemophilus influenzae Rd</td>
</tr>
<tr>
<td>HpalI</td>
<td>C↓C*GG</td>
<td>Haemophilus parainfluenzae</td>
</tr>
<tr>
<td>MspI</td>
<td>C*↓CGG</td>
<td>Moraxella species</td>
</tr>
<tr>
<td>PstI</td>
<td>CTGCA*↓G</td>
<td>Providencia stuartii 164</td>
</tr>
<tr>
<td>PvuII</td>
<td>CAG↓C*TG</td>
<td>Proteus vulgaris</td>
</tr>
<tr>
<td>SalI</td>
<td>G↓TCGAC</td>
<td>Streptomyces albus G</td>
</tr>
<tr>
<td>TaqI</td>
<td>T↓CGA*</td>
<td>Thermus aquaticus</td>
</tr>
<tr>
<td>XhoI</td>
<td>C↓TCGAG</td>
<td>Xanthomonas holcica</td>
</tr>
</tbody>
</table>
Restriction Enzymes

**AluI**

5’ ...AGCT... 3’
3’ ...TCG... 5’

**HaeIII**

5’ ...GGCGC... 3’
3’ ...CCGGG... 5’

**BamHI**

5’ ...GGATCCC... 3’
3’ ...CCATGG... 5’

**HindIII**

5’ ...AAGCTT... 3’
3’ ...TTGCAAA... 5’

**EcoRI**

5’ ...GAATTC... 3’
3’ ...CTTAAG... 5’

**AluI** and **HaeIII** produce blunt ends.

**BamHI**, **HindIII** and **EcoRI** produce “sticky” ends.
Restriction Enzyme Example

-TaqI

-Cuts between T and C
-Leaves sticky end CG
How is DNA fingerprint produced using RFLP?

- Step #3 - The pieces of DNA are then separated according to size by a process called gel electrophoresis:
  - The DNA is loaded into wells at one end of a porous gel, which acts a bit like a sieve.
  - An electric current is applied which pushes the negatively-charged DNA through the gel.
  - The shorter pieces of DNA move through the gel easiest and therefore fastest.
  - It is more difficult for the longer pieces of DNA to move, so they travel slower.
  - As a result, by the time the electric current was switched off, the DNA pieces have been separated by size.
    - *The smallest DNA molecules are furthest away from where the original sample was loaded on to the gel.*
How is DNA fingerprint produced using RFLP?

- Step #4 - The pieces of DNA are transferred or ‘blotted’ out of the fragile gel onto a piece of nylon membrane.
- Step #5 - The nylon membrane is incubated with radioactive Ethidium Bromide to stain the DNA and make it visible.
  - **Ethidium bromide**, a fluorescent dye used for staining nucleic acids. *It is a known mutagen and should be handled as a hazardous chemical.*
  - **Methylene Blue** can be used as a dye to visualize the DNA as well. *This is what we will use in class.*
- Step #6 - The band pattern is then visualized by exposing the nylon membrane to X-ray film.
– When adequate migration has occurred (30 – 50 min. at 100 - 200 volts), DNA fragments are visualized by staining.

– Be aware that DNA will diffuse within the gel over time, and examination or photography should take place shortly after completing.
Migration of DNA Fragments in Agarose

- Fragments of linear DNA migrate through agarose gels with a mobility that is inversely proportional to their molecular weight. In other words, longer fragments move slower than shorter ones.

- So fragments are separated by size in the gel. Long ones stay close to the wells, short ones move farther away.
DNA Fingerprinting Process Example
How is DNA Used in Forensic Cases

– Most often used in rape cases. More than 2 out of 3 cases involve rape.
– The goal is to find a match between evidence from a crime scene and suspect.
– The victim’s DNA is also profiled for purposes of comparison.

Challenges

• Mixtures of DNA samples are difficult because they cannot be unmixed.
• DNA is often degraded in some cases to the point where it becomes useless.
Use of DNA in Human Identification

- Forensic cases -- matching suspect with evidence
- Paternity testing -- identifying father
- Historical investigations
- Missing persons investigations
- Mass disasters -- putting pieces back together
- Military DNA “dog tag”
- Convicted felon DNA databases
How is DNA Evidence Used?

• DNA collected from a crime scene can either link a suspect to the evidence or eliminate a suspect, similar to the use of fingerprints.
• DNA can identify a victim through DNA from relatives, even when no body can be found.
How is DNA Evidence Used?

- DNA can link crime scenes together by linking the same perpetrator to different scenes locally, statewide, and across the nation.
- DNA can place an individual at a crime scene, in a home, or in a room where the suspect claimed not to have been.
- DNA can refute a claim of self-defense and put a weapon in the suspect's hand.
- It can change a suspect’s story from an alibi to presence at a crime scene.
Sources of Biological Evidence

- Blood
- Semen
- Saliva
- Urine
- Hair
- Teeth
- Bone
- Tissue
What Factors Can Affect DNA Evidence?

- Several factors can affect the DNA left at a crime scene.
  - **Environmental factors:**
    - heat
    - sunlight
    - moisture
    - bacteria and mold.

- Therefore, not all DNA evidence will result in a usable DNA profile.

- DNA testing also cannot identify **when** the suspect was at the crime scene or **for how long**.
DR. Sam Shepherd – An example of the use of DNA that is Decades old to solve a crime.
What is a Marker?

- It is a known piece of DNA that is digested with a specific restriction enzyme.
- When this happens, bands of known size (base pair number) are produced.
- These bands are then used to determine the size of the DNA fragments in all other bands on the gel.
An attempt to determine the identity of an unknown father.
What is CODIS?

- **CODIS** stands for **CO**mbined **DNA** **Index** **System**
- CODIS is an electronic database of DNA profiles that can identify suspects.
- DNA profiles from individuals convicted of certain crimes, such as rape, murder, and child abuse, and other violent crimes are entered into CODIS and help officers identify possible suspects when no prior suspect existed.
CODIS Background

– CODIS began as a pilot project in 1990 serving 14 state and local laboratories.

– Then, the DNA Identification Act of 1994 (Public Law 103 - 322) was passed.

– It formalized the FBI's authority to establish a national DNA index for law enforcement purposes.

– October 1998, the FBI's National DNA Index System (NDIS) became operational.

– CODIS became the software portion of NDIS.
NDIS

- NDIS is the highest level in the CODIS hierarchy.
  - SDIS (State Level) is under that.
  - LDIS (Local Level) is under that.
- Enables the laboratories participating in the CODIS Program to exchange and compare DNA profiles on a national level.
How NDIS Works

- CODIS generates investigative leads in crimes where biological evidence is recovered from the crime scene using two indexes: the forensic and offender indexes.
NDIS Sub-Indexes

– The **Forensic Index** contains DNA profiles from crime scene evidence.
NDIS Sub-Indexes

– The **Offender Index** contains DNA profiles of individuals convicted of sex offenses (and other violent crimes) with many states now expanding legislation to include other felonies.
The Initial CODIS Pilot Data:
– Matches made in the Forensic Index can link crime scenes together; possibly identifying serial offenders.
– Based on a match, police in multiple jurisdictions can coordinate their respective investigations, and share the leads they developed independently.
– Matches made between the Forensic and Offender indexes provide investigators with the identity of the perpetrator(s).
– After CODIS identifies a potential match, qualified DNA analysts in the laboratories contact each other to validate or refute the match.
Participating States

- April 2004 - 49 States, US Army, the FBI, and Puerto Rico
- All states currently participate in NDIS except for Mississippi
Statistics:
- As of April 2004 the profile composition of the National DNA Index System (NDIS) is as follows:
  - 2004 Total number of profiles: 1,762,005
  - Total Forensic profiles:
    - 2004 = 80,302
    - 2016 = 684,519
  - Total Convicted Offender Profiles:
    - 2004 = 1,681,703
    - 2016 = 2,205,768
  - Arrestee Profiles (2016) = 2,258,693
  - As of February 2016, CODIS has produced over 322,011 hits assisting in more than 309,614 investigations.
## Utah Codis/NDIS Data

<table>
<thead>
<tr>
<th>Statistical Information</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offender Profiles</td>
<td>97,159</td>
</tr>
<tr>
<td>Arrestee</td>
<td>4,543</td>
</tr>
<tr>
<td>Forensic Profiles</td>
<td>987</td>
</tr>
<tr>
<td>NDIS Participating Labs</td>
<td>1</td>
</tr>
<tr>
<td>Investigations Aided</td>
<td>88</td>
</tr>
</tbody>
</table>
Brief History of Forensic DNA Typing

– 1984 Dr. Alec Jefferys - Leicester University in England. Gave the name to this process – genetic fingerprinting.
  – Jefferys also discovered particular locations of the DNA ladder where repetitive patterns show the greatest variability in the number of times they repeat.
– 1985 - first paper on PCR
– 1988 - FBI starts DNA casework
– 1991 - first STR paper
– 1995 - FSS starts UK DNA database
– 1998 - FBI launches CODIS database
Example from 1985

Example of gel from 1985
The case involved a two year struggle by Christiana Sarbah and her son, Andrew, to prove to the Home Office in England that they were, indeed, mother and son. The ordeal began in 1983 when Andrew, then 13, arrived in England after a long stay in Ghana with Christiana's estranged husband. Immigration officials held him at Heathrow Airport, claiming his passport was forged, or that a substitution had been made. Only after intervention by a Member of Parliament was Andrew allowed to stay at his family's home in London.
Hammersmith Law Centre, which provides legal aid to the underprivileged, amassed huge amounts of evidence, including photographs & statements by family members. Various tests to determine genetic characteristics showed that Christiana and Andrew were almost certainly related.

However, the tests could not determine whether Christiana was his mother or merely an aunt.

After reading in the local newspaper about a scientific discovery that could prove maternity, Centre workers contacted Alec Jeffreys at Leicester University, and asked him to take on the case. Jeffreys accepted, believing it would be an ideal test of the DNA fingerprint technology he had recently developed.

Jeffreys used DNA extracted from blood samples from Christiana, Andrew, an unrelated individual, and Christiana's three undisputed children. Jeffreys produced the DNA fingerprints seen at the right.
He compared the banding patterns of all the individuals. Alec Jeffreys showed that Andrew's DNA fingerprint contained about 25 bands that were inherited from his mother. The possibility that Christiana is the "true" mother's sister is one in 600,000.

Although Andrew's father's DNA was not available, Jeffreys reconstructed the father's DNA fingerprint from bands present in Christiana's three other children, but absent in Christiana.

About half of Andrew's bands match bands in the father's compilation and the remaining bands were all present in Christiana's fingerprint.

The possibility of this happening by chance is less than one in a trillion.

The Home Office accepted the DNA fingerprint evidence, and allowed Andrew to stay in England with his mother and siblings. The Home Office also announced that it would not contest future immigration cases if similar DNA evidence were available.
First Use of DNA Fingerprinting in a Criminal Case:
State of Florida vs. Jones and Reesh (The Murders at Rodman Dam)
In July 1987, Randall Scott Jones and Chris Reesh, both teenagers, were shooting with a 30/30 hunting rifle at Rodman Dam recreation area in Florida. While they were shooting, Jones' pickup truck became stuck in a sandpit. A fisherman suggested they ask a couple in a pickup parked nearby for help. Jones and Reesh approached the truck, where Kelly Lynn Perry and her fiancé, Matthew Brock, were sleeping. The two men debated whether or not to wake them to ask for assistance. The following morning, fishermen found the bodies of Perry and Brock in the woods adjacent to the recreation area.

Police investigated and revealed that each had been shot in the head with a 30-caliber bullet and that Perry had been sexually assaulted. Their pickup was reported stolen. In August, Jones was arrested in Mississippi found driving Brock's pickup. Reesh was arrested the next day in Palakta, Florida, after Jones told police that they were together that night in July. Both were indicted on counts of first-degree murder and sexual battery.
A semen sample, retrieved from Perry's body, and blood samples from Reesh, and Jones, were compared at a laboratory that specializes in DNA fingerprint testing.

Using the results of the DNA fingerprint and other evidence, officials were able to piece together the events of the crime:

- Without waking the couple in the pickup, Jones shot both Perry and Brock in the head at close range. He and Reesh then dragged the bodies into the woods nearby. They towed Jones' truck from the sand with Brock's pickup and left with both trucks.
- Later Jones returned to the crime scene, moved the bodies further into the woods, and raped Perry.
- A representative from the DNA fingerprinting laboratory tested that the chance of another person having the same DNA fingerprint as Jones was one in 9,390,000,000 about twice the earth's population (at the time).
- After deliberating only 15 minutes, the jury convicted Jones of murder and rape.
- The judge sentenced him to a double death sentence, making the first case involving DNA fingerprint evidence in U.S. legal history in which the death sentence was handed down.
- Reesh was sentenced to six years in prison and twenty years probation (because he didn’t pull the trigger or rape the woman).
Murder at Rodman Dam

1988
First Case using DNA fingerprinting (in the USA) to hand down death penalty.
DNA numbers are merely a means of stating the chances of particular matches to occur.
Accuracy of DNA Evidence

- Assuming that investigators properly collect & handle evidence, and that the forensic scientists employ accepted methods and conduct the analysis correctly, DNA evidence is extremely accurate.

- The chances of one individual’s DNA profile matching another person’s are extremely small. About one in a billion by some estimates. When comparing the band patterns in a profile, numbers grow exponentially (100 x 100).

- Consider that there are over 7 billion people on Earth right now:
  - 1 DNA fragment match could happen in 1/100 people.
  - 2 DNA fragment matches = happen in 1/10,000.
  - 3 DNA fragment matches = 1/1,000,000.
  - 4 DNA fragment matches = 1/100 million.
  - 5 DNA fragment matches = 1/10 billion.

- Compared to eyewitness testimony, DNA evidence is a highly effective way to match a suspect to a crime scene.

- Because of its accuracy, criminal lawyers increasingly rely on DNA evidence to prove a defendant’s guilt or innocence.

- DNA evidence has also exonerated people through post-conviction analysis of biological samples.