Illegal Ivory Trade Analysis

DATASCI 205 | Fall 2025 | Section 4

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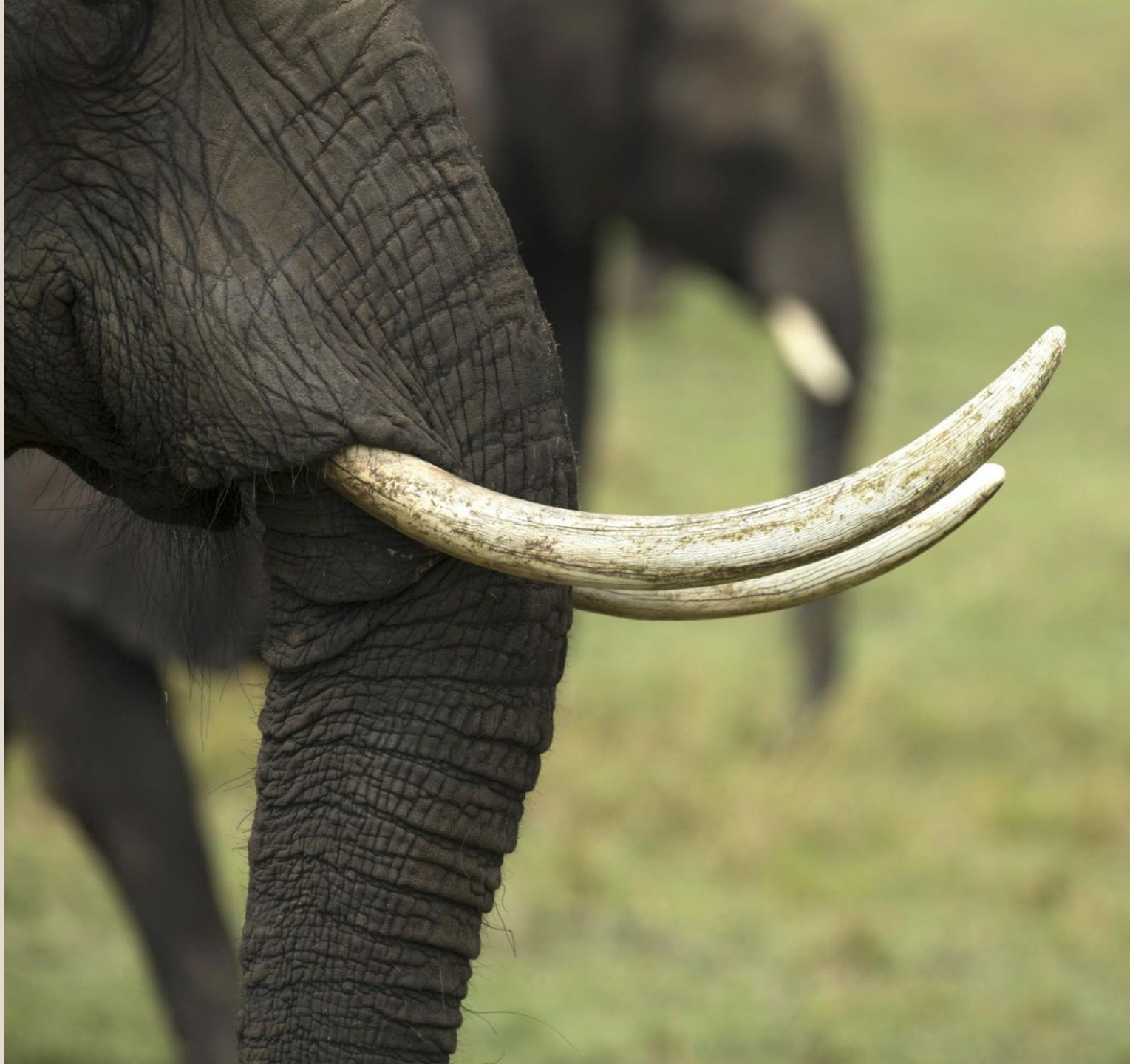
AGENDA

Business Case Scenario

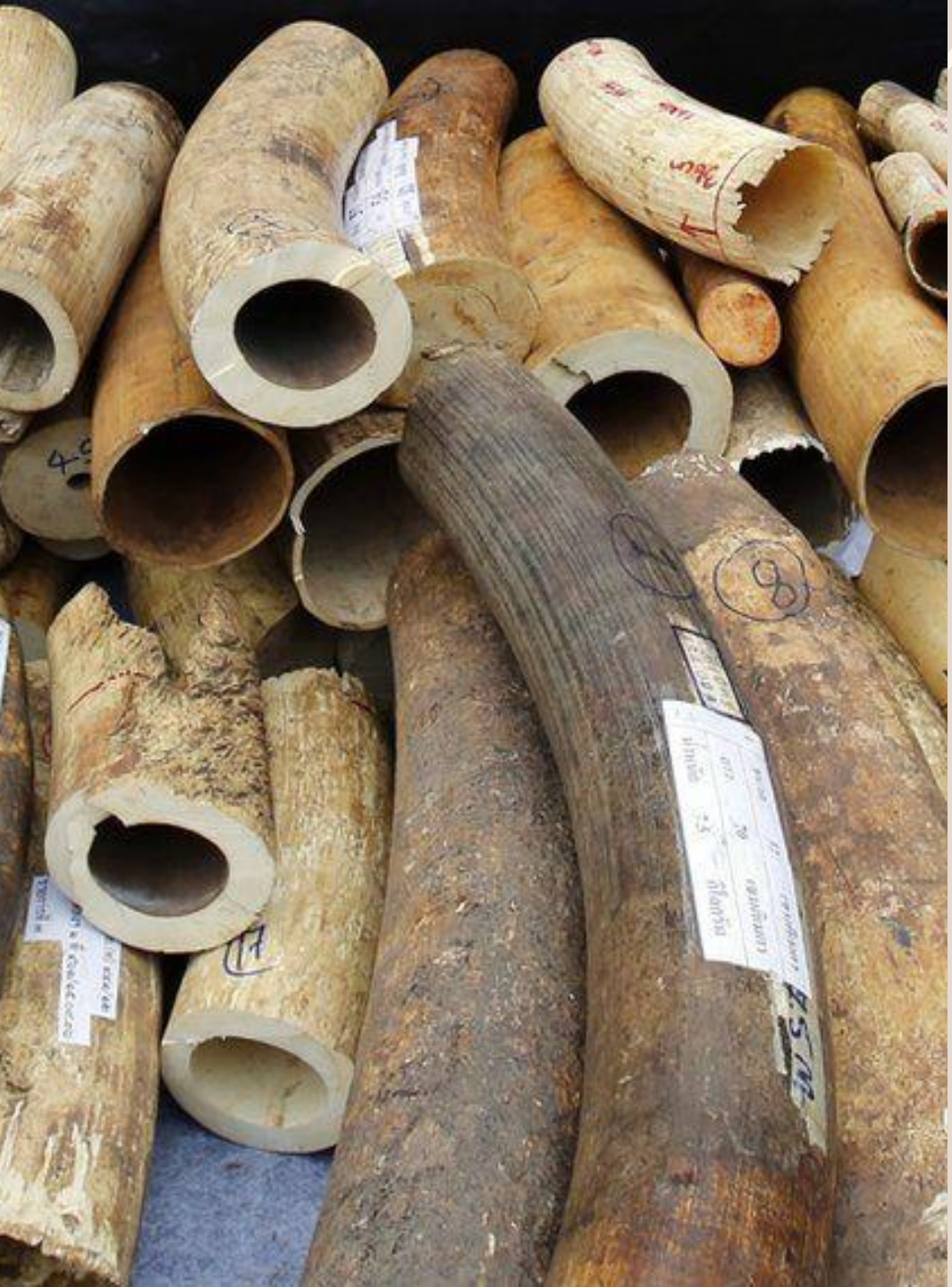


Monitoring High-Risk Elephant Ivory Trade

- Global ivory trade bans have reduced legal trade, but it still occurs with high restrictions
  - All elephant species are endangered, largely due to poaching to acquire ivory

- We must identify which countries and trade routes are still active
  - Enact and enforce stricter legislation

- CITES
  - The Convention on International Trade in Endangered Species of Wild Fauna and Flora
  - International agreement between governments
  - Database enables analysis of global wildlife trade networks
  - ***Ensure international trade of wild animal and plant specimens doesn't threaten the survival of those species***



Data Description

CITES Trade Database

- Reported trades between 180+ countries, 1975 - 2025

- Data structure
  - Each row represents a trade transaction reported by importer and/or exporter of the product
  - > 25 million records

- Key trade attributes
  - Importer, exporter (trade route)
  - Origin (biological origin)
  - Species (taxon, family)
  - Term (specimen description)
  - Quantity, unit (standardized measures for each species)

Extracting Elephant Ivory Trades

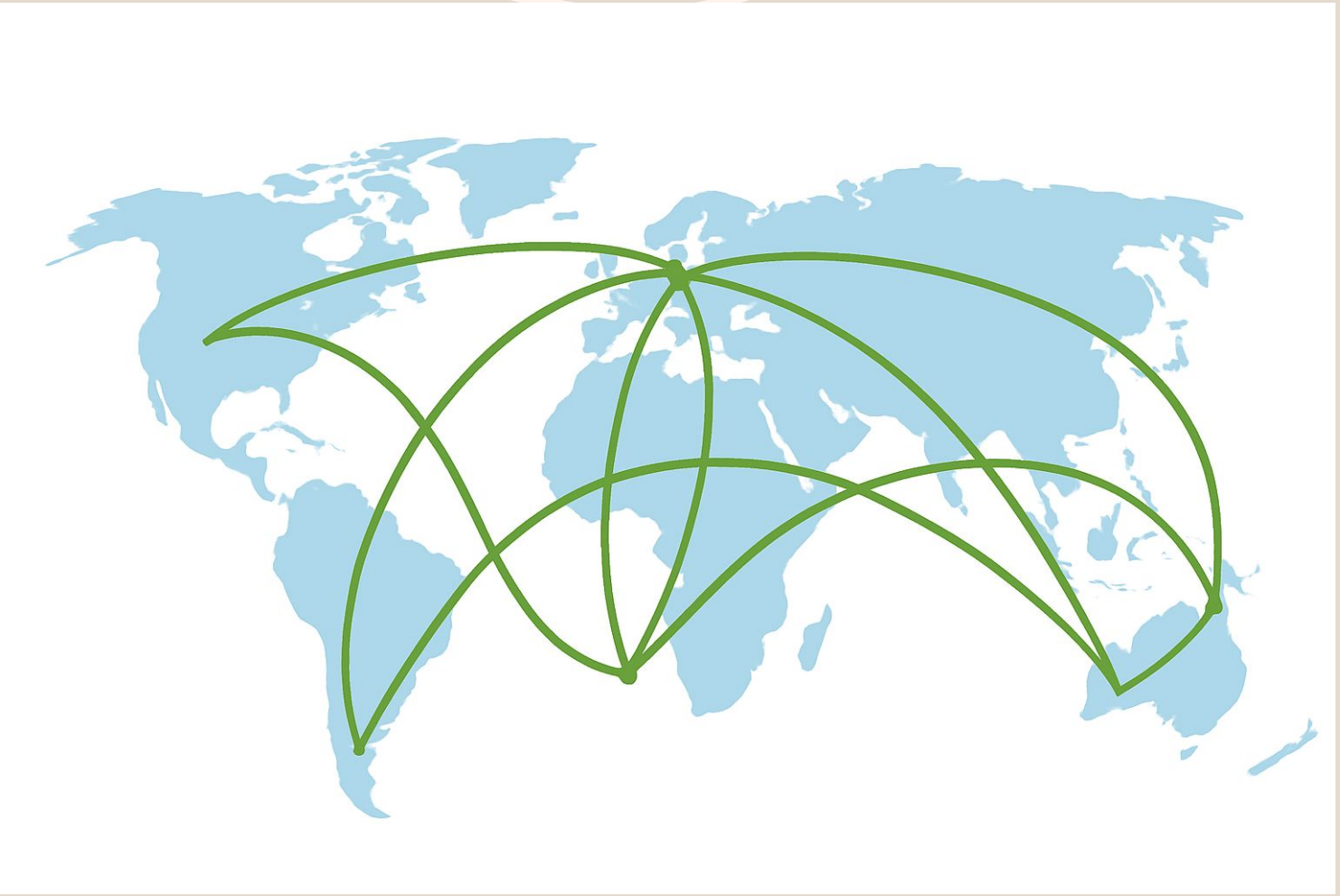
~195,000 trades containing ivory from elephants between 1976 and 2024

- Family
  - Elephantidae (all African and Asian elephants)

- Term
  - Ivory
  - Tusks
  - Piano keys

- Units
  - Number of specimens (most common reported unit)
  - **No clear conversion between all units available (kg, oz, number of specimens, cartons etc.)*

- Known importer *and* exporter



Graph Design

Inbound Trade Network

- Nodes
  - Countries (importers, exporters, origin)

- Relationships
  - Imported from
    - Weighted by total number of specimens traded
  - Imports originated from
    - Weighted by total number of specimens traded (where origin is populated)

- Addressing ivory trade concerns
  - ***Identify*** direct trade routes, major exporters of ivory (where is ivory being imported from)
  - ***Identify*** biological origins of traded ivory
  - ***Implement*** strict policy regulations in major export hubs and ivory sources

- Graph design enables more efficient analysis than relational databases
  - Trade flows naturally form a network (track routes, hubs, intermediate connections)
  - Relational database requires complex queries and joins to achieve same insights

Graph Database Selection Framework

	Neo4j	MongoDB	Redis	Relational DB
Use case fit	Connected Data w/ Relationships	Flexible, Semi-Structured Data	Real-time Analytics	Structured Data
Example use cases	Trafficking Hotspots & Routes	Variable Species Trafficking Data	Real-time Trafficking Detection	Storing Trafficking Data
Graph capability	Cypher Query	Non-native	RedisGraph module	Non-native
Performance	Deep relationship queries	Document lookups	Speed	Analytical queries
Scalability	High V, Moderate H	High H	High V, High H (Redis Cluster)	High V
Visualization	Built-in tools (Bloom, GDS)	Basic Visualization (MongoDB Charts/ Compass)	External Tools Only	External Tools

Using MongoDB for Ivory Trade Intelligence

Business goal: build a flexible "case file" store for ivory trade investigations

Each **document = one shipment / incident / route pattern**

Document combines:

- CITES trade data (origin, destination, term, quantity)
- Seizure & enforcement metadata
- Route info (transit countries, ports)
- Neo4j graph metrics
- Free-text notes and comments

Supports multiple **analytical POVs** on the same data (by exporter, importer, transit route, network, year)

Why MongoDB (vs Relational)

Evolving, messy schema:

- Different countries / years report different fields
- New risk attributes appear over time → MongoDB lets us add fields without schema migrations

Denormalized "case file" view:

- Analysts usually want the **whole case** at once, not 6–8 joined tables
- Nested structures (routes, multiple agencies, multiple notes) map naturally to JSON arrays/subdocuments

Relational DB still used as SOR:

- Clean, normalized CITES tables stay in Postgres as **system of record**
- MongoDB is a **supplemental analytical store**, optimized for exploration and investigator workflows

Redis for Real-Time Ivory Risk & Alerts

Business goal: support **live monitoring** for enforcement agencies

- "Which shipments/routes are highest-risk *right now*?"
- Fast API / dashboard lookups to decide which containers to inspect
- Live ranking board of risky shipments.

For each **active shipment**, we compute a **risk_score** using:

- Neo4j graph metrics (country PageRank, route betweenness, communities)
- Historical seizure patterns, quantity

Why Redis Fits Better Than Relational Database

In-memory, key–value access:

- Extremely low latency for frequent reads/writes from dashboards and APIs
- Perfect for "hot" data that changes quickly (risk scores, alerts, leaderboards)

Ephemeral, derived data:

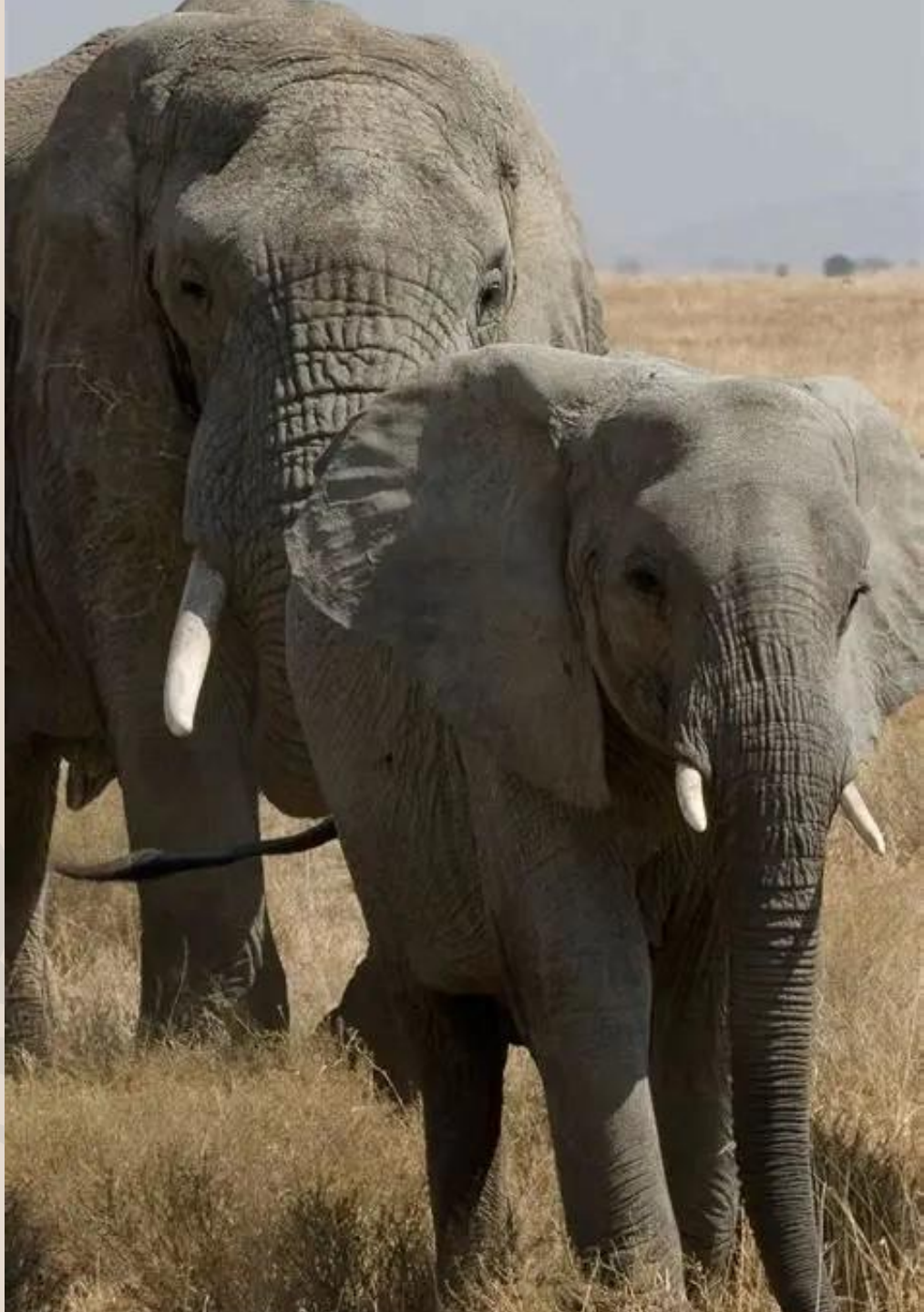
- Risk scores can be recomputed from Neo4j + history
- We don't need full ACID durability for this cache
- Built-in **TTL** is ideal for short-lived shipment state

Native data structures (sorted sets):

- "Top N high-risk shipments/routes" is a single Redis query
- Doing this in a relational DB would require heavy indexing, materialized views, and complex queries

Relational DB remains for historical trade records; Redis is the real-time "nervous system" for current ivory trafficking risk

Graph Algorithms & Analysis



Top Ivory Export Hubs (PageRank Analysis)

Business Question: What countries function as the most influential global hubs, those that shape, retribute, or anchor the global ivory trade network?

PageRank score is determined by how many connections point to a country and how influential those connected countries are, weighted by the volume of ivory flowing along these connections.

Rank	Country	PageRank Score
1	China (CN)	26.5
2	Hong Kong (HK)	25.5
3	Zimbabwe (ZW)	18.0
4	Botswana (BW)	17.1
5	United Kingdom (GB)	14.8
6	Zambia (ZM)	6.8
7	India (IN)	6.4
8	United States (US)	6.3
9	South Africa (ZA)	5.7
10	Kenya (KE)	5.2

Top Ivory Importers (PageRank Analysis)

Business Question: What countries exert the greatest influence on the global ivory import network, based on only on volumes they ship, but on how central they are to overall trade flows?

PageRank score is determined by how many destinations a country imports ivory from, how influential those destination countries are, and how much ivory flows along each import link.

Rank	Country	PageRank Score
1	United States (US)	44.7
2	Canada (CA)	20.7
3	Hong Kong (HK)	15.9
4	Germany (DE)	15.1
5	Japan (JP)	13.7
6	United Kingdom (GB)	13.5
7	Switzerland (CH)	6.9
8	France (FR)	6.6
9	Italy (IT)	3.1
10	Denmark (DK)	2.7

Top Global Middleman Countries (Betweenness Centrality)

Betweenness centrality: Measures how often a country lies on the shortest trade paths between other exporting and importing countries. These are key middlemen, transit hubs or bottleneck countries facilitating global ivory movement.

Key Findings: The U.S. is the #1 global transit hub, meaning ivory flows between many countries depend on routes passing through the U.S.

Rank	Country	Betweenness
1	United States (US)	10,045
2	Switzerland (CH)	7,563
3	Germany (DE)	6,032
4	Zimbabwe (ZW)	5,611
5	Canada (CA)	5,569
6	New Zealand (NZ)	5,055
7	United Kingdom (GB)	4,000
8	France (FR)	3,625
9	Spain (ES)	3,244
10	Netherlands (NL)	3,179

Top 10 Exporter – Destination Ivory Flows

Business Question:
Where do ivory-exporting countries send the largest volumes of ivory?

Key Findings: China to Hong Kong is by far the largest global ivory trade corridor. Hong Kong acts as the re-export hub shipping large volumes to U.S., Japan, Germany, and Italy.

Rank	Exporter	Destination	Total Ivory Volume
1	China (CN)	Hong Kong (HK)	115,895,839
2	Hong Kong (HK)	United States (US)	35,130,640
3	Hong Kong (HK)	Japan (JP)	31,578,157
4	Hong Kong (HK)	Germany (DE)	3,140,050
5	Hong Kong (HK)	Italy (IT)	1,871,110
6	United Kingdom (GB)	Germany (DE)	1,783,435
7	India (IN)	United States (US)	1,401,065
8	Taiwan (TW)	Japan (JP)	1,014,246
9	China (CN)	Thailand (TH)	1,000,018
10	India (IN)	Germany (DE)	966,226

Top 10 Importer – Origin Ivory Flows

Business Question: From which origin countries do the world's largest ivory importers source the most ivory?

Key Findings: Hong Kong is the single largest importer of ivory, especially from Central African Republic. U.S. imports large volumes from Democratic Republic of Congo.

Rank	Importer	Origin	Total Ivory Volume
1	Hong Kong (HK)	Central African Republic (CF)	43,461,560
2	United States (US)	Democratic Republic of Congo (CD)	13,717,330
3	Japan (JP)	Republic of Congo (CG)	2,266,172
4	Thailand (TH)	Zimbabwe (ZW)	1,000,000
5	Romania (RO)	Kenya (KE)	721,977
6	Germany (DE)	Sudan (SD)	469,645
7	Denmark (DK)	Sudan (SD)	425,082
8	France (FR)	Sudan (SD)	93,076
9	United Kingdom (GB)	Sudan (SD)	81,936
10	Canada (CA)	Central African Republic (CF)	59,066

Key Insights and Recommendations

Key Insights

Theme	Key Insights
Global Network Structure	• Ivory trade forms a dense, highly connected global network. • Small number of countries act as dominant import, export, and transit hubs.
Importer Network	• Top import influencers (PageRank): US, CA, HK, DE, JP, GB. • Most direct suppliers (Degree): US, GB, CA, CH, DE. • Key middlemen (Betweenness): US, CH, DE, NZ, CA, GB. • Most central (Harmonic): ZW, ZA, GB, US, FR.
Exporter Network	• Largest export hubs (Degree): ZW, ZA, GB, US, FR. • Top export influencers (PageRank): US, CA, HK, DE, JP. • Key transit intermediaries (Betweenness): US, HK, GB.
Dominant Trade Corridors	• Largest exporter → destination: CN → HK (~115M). • Largest importer → origin: HK ← CF (~43M). • Hong Kong serves as the major global redistribution hub.
Supply Chain Roles	• Africa: Primary origins + central supply nodes (ZW, ZA, BW, TZ). • Hong Kong: Global re-export gateway. • US/EU: Major demand + transit markets (US, DE, CH, GB).
Overall Insight	• Ivory flows follow a predictable pattern: African origins → Asian transit hubs → Global markets. • Enforcement and monitoring should focus on Hong Kong, US, EU, and core African supply nodes.

Recommendations

- Target enforcement at major global transit hubs, such as Hong Kong (HK), the United States (US), Germany (DE), and the United Kingdom (GB) where the majority of ivory shipments are routed and re-exported.
- Strengthen border controls in core African source countries like Zimbabwe (ZW), South Africa (ZA), Botswana (BW), Tanzania (TZ), and Malawi (MW), and require digital tracking of high-risk exports departing ports in these countries.
- Coordinate monitoring along the largest ivory corridors, for example China to Hong Kong, Hong Kong to United States, and Central African Republic (CF) to Hong Kong in order to disrupt trafficking routes.

Thank You!

Questions?

APPENDIX

Outbound Trade Network

- Nodes
  - Countries (importers, exporters, origin)
- Relationships
  - Exported to
    - Weighted by total number of specimens traded
  - Exports originated from
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- Addressing ivory trade concerns
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  - ***Identify*** biological origins of traded ivory
  - ***Implement*** strict policy regulations in major import hubs and ivory sources
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Top Countries by Degree Centrality (Direct Export Connections)

Degree centrality: Measures how many different countries each exporter sends ivory to , indicating the breadth and reach of their export network

Key Findings: Zimbabwe and South Africa have the largest number of direct export connections. European hubs like U.K., France, Germany, and Switzerland appear as key redistribution points for ivory leaving Africa.

Rank	Country	Degree
1	**Zimbabwe (ZW)**	150
2	**South Africa (ZA)**	112
3	**United Kingdom (GB)**	100
4	**United States (US)**	98
5	**France (FR)**	85
6	**Germany (DE)**	75
7	**Switzerland (CH)**	74
8	**China (CN)**	67
9	**Tanzania (TZ)**	65
10	**Botswana (BW)**	63

Top Countries by Degree Centrality (Direct Import Connections)

Degree centrality: Measures how many direct import relationships a country has, i.e., how many different countries it receives ivory from.

Key Findings: The U.S., U.K., and Canada have the widest supplier networks, importing ivory from the largest number of distinct trading partners.

Rank	Country	Degree
1	**United States (US)**	168
2	**United Kingdom (GB)**	126
3	**Canada (CA)**	104
4	**Switzerland (CH)**	94
5	**Germany (DE)**	94
6	**France (FR)**	88
7	**Italy (IT)**	74
8	**Australia (AU)**	70
9	**Japan (JP)**	68
10	**Spain (ES)**	63

Top Countries by Harmonic Centrality

Harmonic centrality: Reveals which countries are most centrally positioned in the ivory network, regardless of direct connections.

Key Findings: Zimbabwe and South Africa are at the very top while U.K. and U.S. also score highly. European countries (GB, FR, DE, CH) form a dense central cluster. Multiple African countries (NW, BW, TZ) appear, reflecting their central role in the supply chain.

Rank	Country	Harmonic Centrality
1	**Zimbabwe (ZW)**	0.8041
2	**South Africa (ZA)**	0.7170
3	**United Kingdom (GB)**	0.6884
4	**United States (US)**	0.6847
5	**France (FR)**	0.6404
6	**Germany (DE)**	0.6336
7	**Switzerland (CH)**	0.6299
8	**Malawi (MW)**	0.6081
9	**Botswana (BW)**	0.6059
10	**Tanzania (TZ)**	0.5968