Fermi Estimation:
Reasoning Your Way to a Number



How many piano tuners work in Chicago? Structured reasoning answers this.



A Fermi estimate targets the nearest power of ten, not precision.



Why it matters: sanity-checking claims, sizing problems, planning under uncertainty.



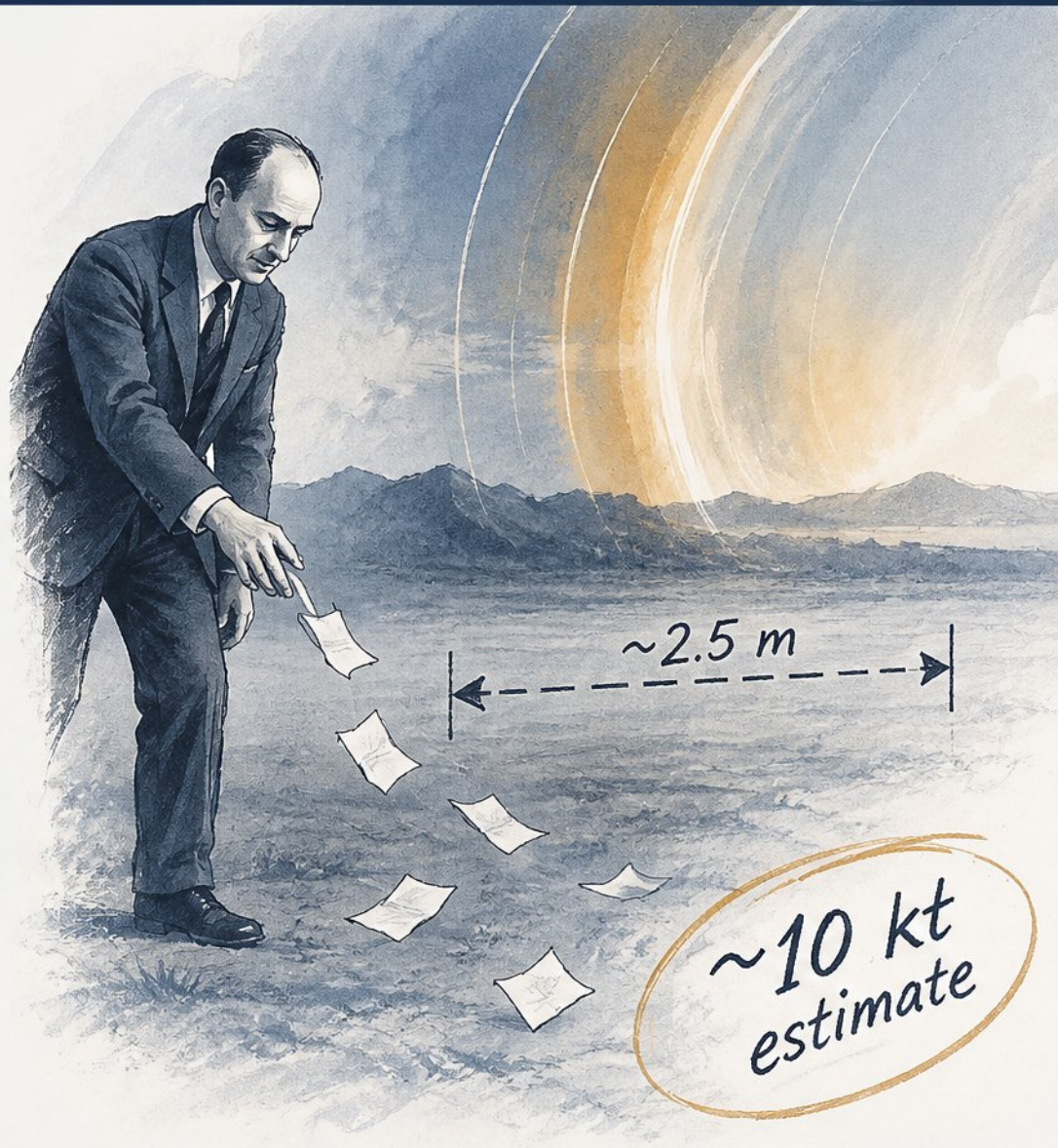
Roadmap: decomposition, anchoring, bounding, calibration, arithmetic, practice.



Ground rules: round aggressively, state assumptions, let errors cancel.

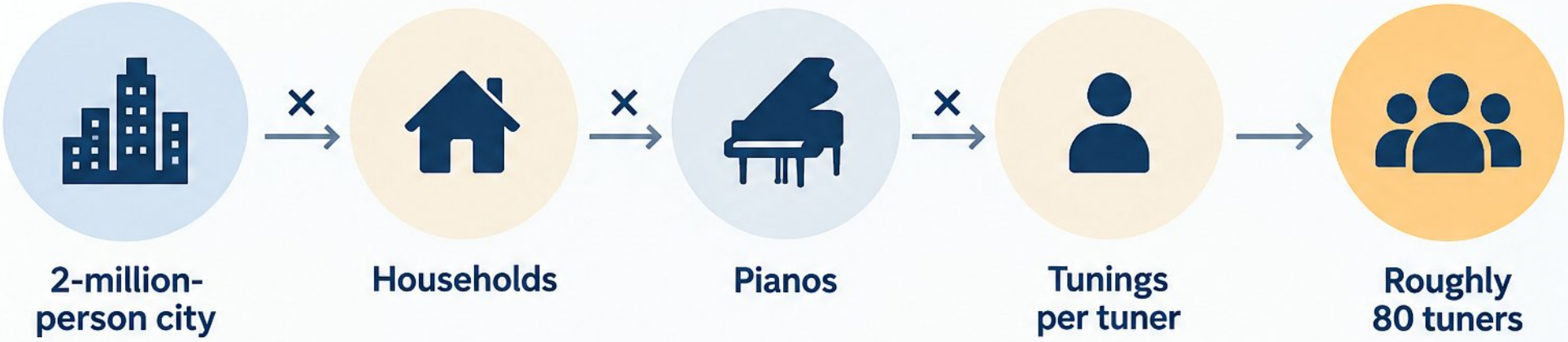
Why Order-of-Magnitude Thinking Matters

- Precision ≠ accuracy: roughly right beats precisely wrong
- Each power of ten is a meaningful, practical step
- Fermi at Trinity: paper scraps moved ~2.5 m → ~10 kt estimate
- Modern radiochemical value ~25 kt; Fermi's estimate served as a useful lower bound
- Use for feasibility checks, budgets, capacity, and fact-checking claims



The Core Method: Decompose, Estimate, Combine

- **Workflow:** clarify the question, set scope and units, then decompose
- **Break unknowns into 3–5** measurable factors you can each estimate
- **Common structures:** rate × time, population × per-capita, density × area
- **Track dimensions as an error check:** people, dollars, kilowatt-hours
- **Round to one significant figure;** save precision for the final step



Building Your Anchor Sheet of Reference Values

- **Anchor types:** populations, rates, densities, per-capita consumption, physical constants
- **World population** ~8×10^9; US ~3×10^8; hours in a year ~9,000
- **Working hours/year** ~2,000; air density ~1 kg/m^3; water/body ~1,000 kg/m^3
- **Radius of Earth** ~6,400 km; Earth–Sun distance ~1.5×10^{11} m
- **Borrow anchors from analogs:** household scale, stadium capacity, class size
- **Bound high and low** before committing to a central value



Bounding: Bracketing the Answer Before Guessing

- Set a lower and upper bound before naming any central value
- Techniques: extreme cases, conservation laws, known limits
- A justified bracket beats false precision; use the geometric mean
- Moose example: person (~10^2 kg) to car (~10^3 kg) → ~3×10^2 kg
- Warning signs: bounds too narrow (overconfidence) or too wide (no information)



Person
(~10^2 kg)





Car
(~10^3 kg)

Lower bound

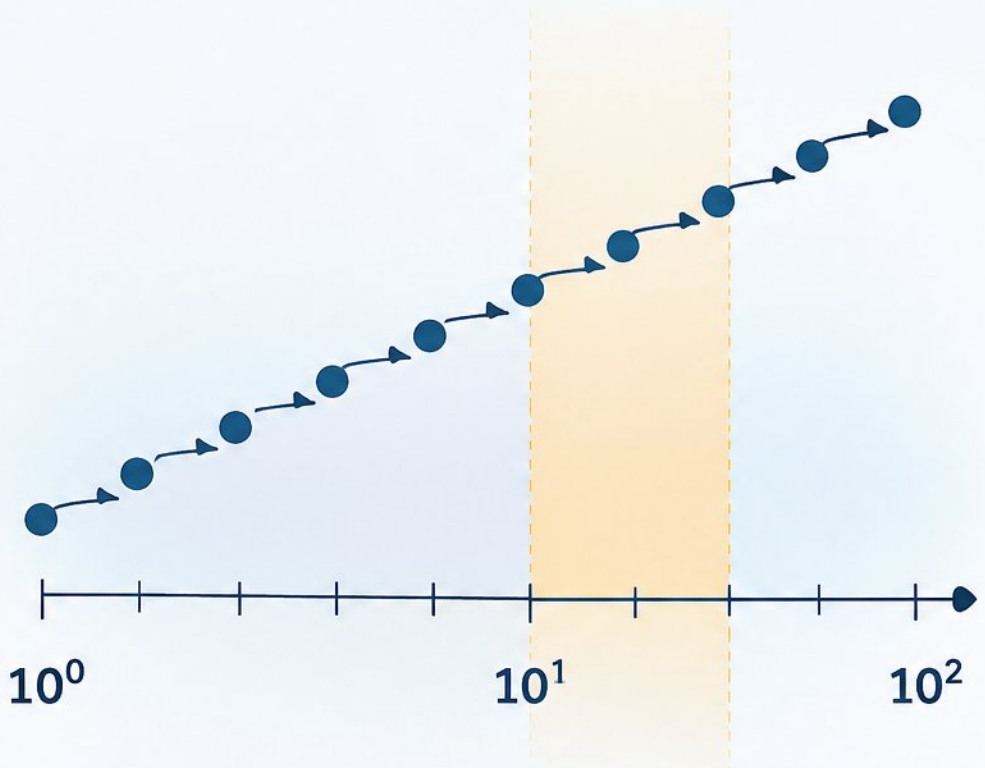
~3×10^2 kg

Upper bound

Quick Arithmetic and Logarithmic Reasoning

- Round every factor to one significant figure before multiplying
- Scientific notation keeps place value visible; multiply left to right
- Work in log space: errors in factors add, not multiply
- Nine factor-of-two errors typically land within one order of magnitude
- Remember $10^{0.5} \approx 3.2$, so 3.2 rounds toward 10
- Watch for unit mismatches and per-day versus per-year mixups

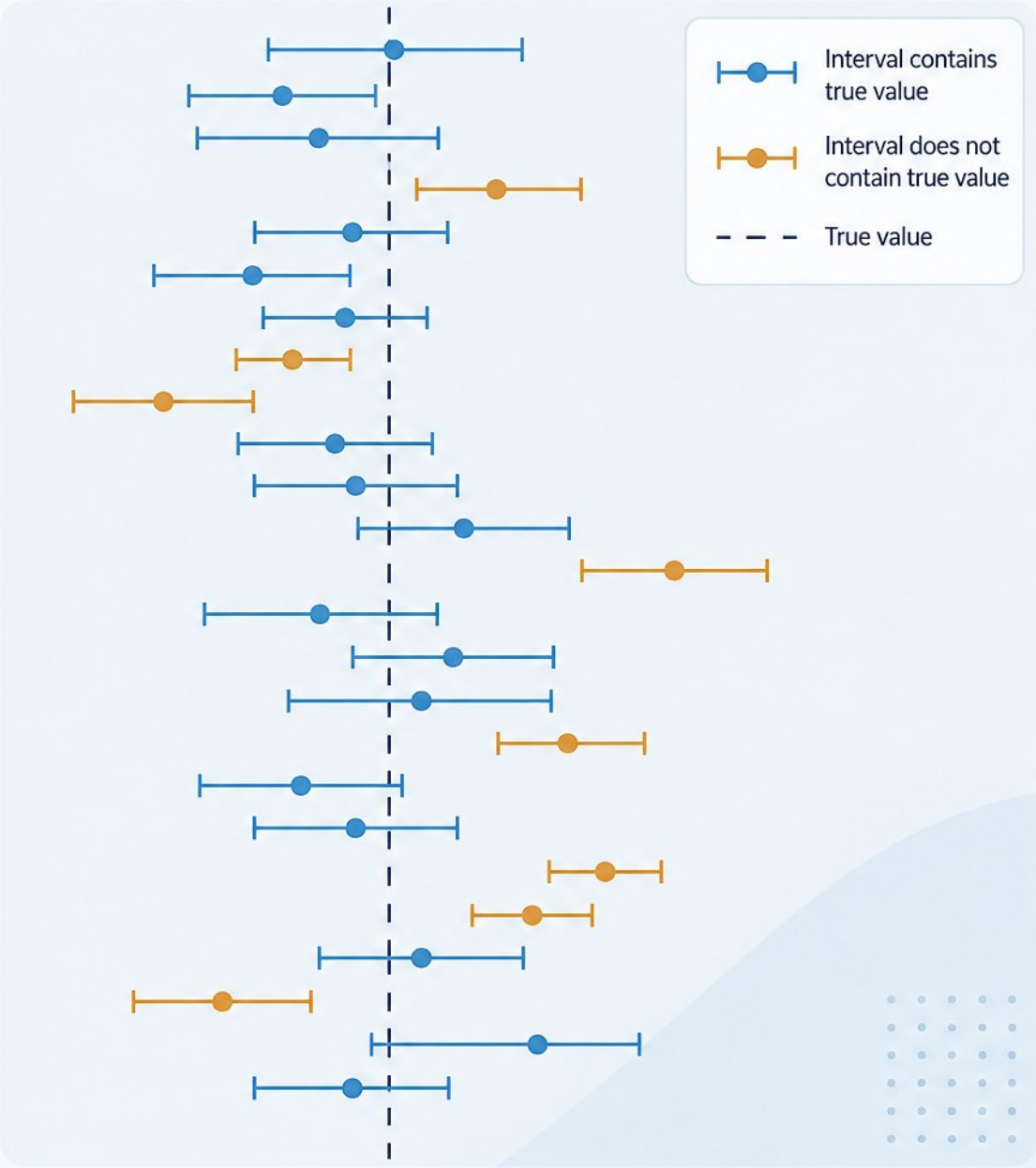
Nine factor-of-two errors on a log scale



Nine factor-of-two errors typically land within one order of magnitude.

Calibration: Are Your 90% Intervals Really 90%?

- **Biases that distort estimates:** anchoring, availability, overconfidence, confirmation bias
- **Well calibrated:** ~18 of 20 stated 90% intervals should contain the true value
- **Typical result:** participants average only ~11 of 20 — intervals are systematically too narrow
- **Fixes:** start with absurdly wide bounds, move inward; equivalent-bet test; premortem; aggregate independent estimates
- **Calibration training works:** analysts improved significantly on interval tasks (d = 1.05)



Estimate Traps and How to Avoid Them



- **Anchoring:** the first number you hear drags your estimate toward it
- **Availability:** vivid, memorable examples feel more representative than they are
- **Agreement isn't accuracy** — collect independent estimates before any group discussion
- **Red-team each estimate:** argue separately why it's too high and too low
- **Separate reducible uncertainty** from irreducible randonmess before chasing more data

Sanity Checks: Dimension, Plausibility, Sensitivity

1

$$\left[\frac{\text{kg}}{\text{kg}}\right]$$

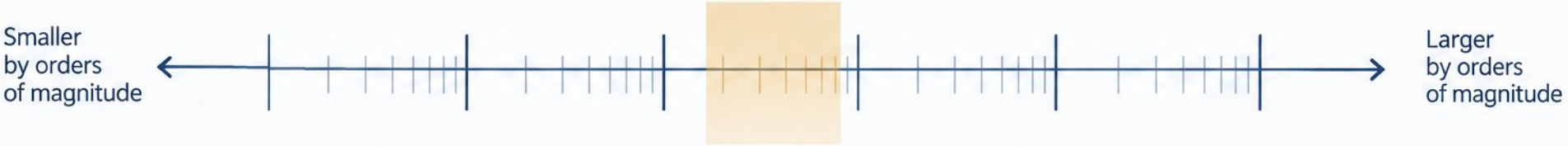
Check 1 — dimensions:
units cancel and final quantity has intended units

2

Check 2 — plausibility:
compare to anchors; too much X means wrong decomposition

3

Check 3 — sensitivity:
vary the dominant factor by 2× and see the swing



Per-capita test:
divide by population; does it make sense per person?

Newspaper test:
would this number look absurd in a headline?

Communicating Estimates Without False Precision

1. Lead with a four-part format: value, range, key assumptions, confidence.
2. Say "about 80, likely 50 to 150" — not "83.7".
3. Use range bars and order-of-magnitude bands, not fine decimals.
4. For decision-makers: implication first, then reasoning chain, then caveats.
5. Write a memo paragraph naming every assumption a reader needs.

MEMO

We estimate the total effort at **about 80, likely 50 to 150.** This estimate assumes a stable scope, an experienced team, and no major external dependencies. We are moderately confident, given typical variability for this type of work and the current level of information.



Key assumptions

- A stable scope
- An experienced team
- No major external dependencies

Caveats

Actual results may be higher or lower if these assumptions change or if new information emerges.

Guided Practice: A Full Fermi Walkthrough

Smartphones in use worldwide

~8 billion people × ~65% penetration → **~5 billion devices**

- Start with a global population
- Apply a penetration rate
- Estimate total devices

Lifetime breaths

15/min × 60 × 24 × 365 × 80 years → **~10^9 scale**

- Start with a breathing rate
- Convert to a day
- Scale to a lifetime
- Estimate total breaths

Class problems: smartphones in use worldwide, or lifetime breaths

Educator script: staged prompts, group checkpoints, common-error list

Debrief: compare group estimates, surface assumptions, reward process

Assessing the Process, Not the Answer

- **Rubric: clarity, decomposition, justified factors, bounds, sanity checks, honest uncertainty**
- **Grading the exact number rewards lucky guessing over good reasoning**
- **Sequence: solo estimate, then pairs, then groups with added constraints**
- **Estimate a verifiable quantity, look it up, compute percent error**
- **Adaptable rubric language spans middle school through professional training**

Rubric Element	What Good Work Looks Like
Clarity	States what is being estimated and interprets it in their own words.
Decomposition	Breaks the problem into smaller, manageable parts.
Justified Factors	Explains why chosen factors are reasonable and relevant.
Bounds	Provides a lower and upper bound to show a plausible range.
Sanity Checks	Checks the result for reasonableness using simple logic.
Honest Uncertainty	Acknowledges limitations and what could change the result.

Transfer: Applying Estimation in Your Own Context

Science education: estimate first, then calculate — builds number sense

Policy: screen proposed figures for plausibility before accepting



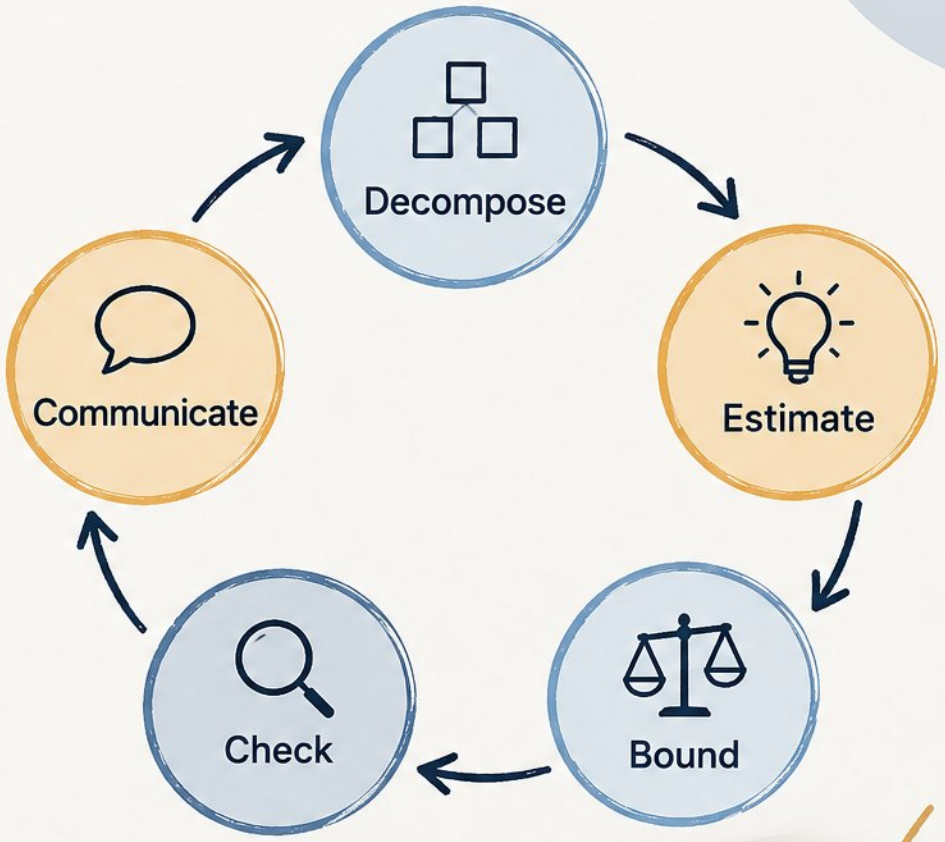
Workplace: capacity planning, budget sizing, feasibility checks

Everyday decisions (you): use estimation to make clearer choices

- **Science education:** estimate first, then calculate — builds number sense
- **Workplace:** capacity planning, budget sizing, feasibility checks
- **Policy:** screen proposed figures for plausibility before accepting
- **Keep a personal anchor sheet** and an estimate log with outcomes
- **Weekly plan:** one Fermi estimate plus a calibration reflection
- **Practice resources:** University of Maryland Fermi Problems, Estimation 180
- **Close the loop:** decompose → estimate → bound → check → communicate

Key Takeaways and Next Steps

1. Fermi estimation is disciplined reasoning, not guessing: every estimate is a model with visible assumptions
2. Aim for the nearest power of ten, bound before you guess, and let independent errors cancel
3. Calibration is trainable: track your hits, widen intervals when overconfident, use feedback
4. The method transfers across science, business, policy, and daily life
5. Your next step: run one full loop this week and record it in your estimate log





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