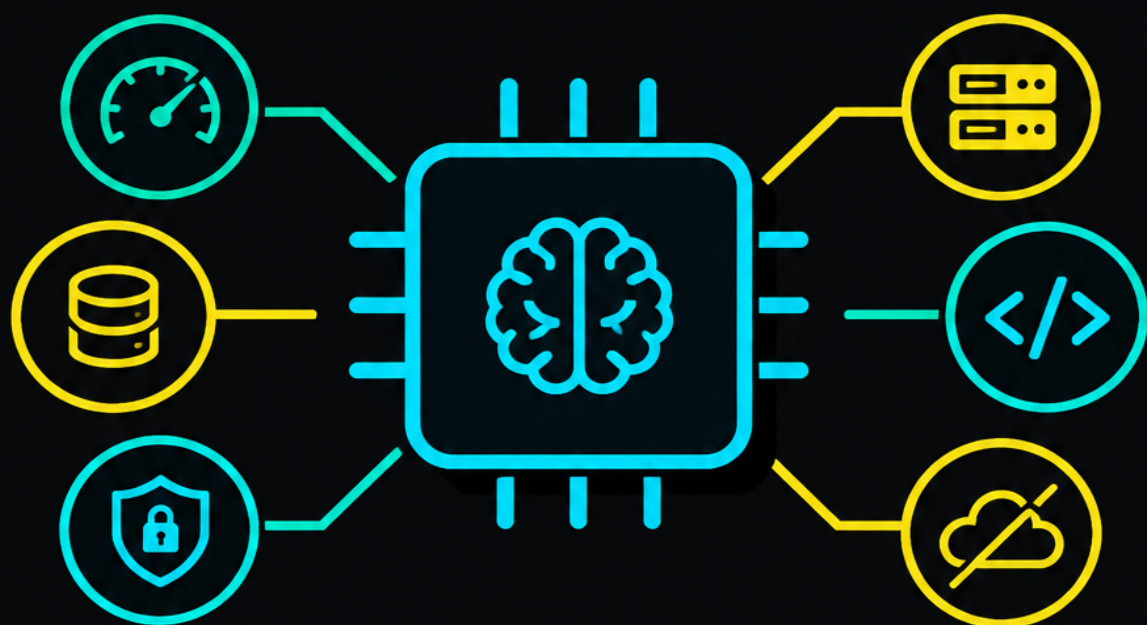


BUILDING SMALL, FAST, PRIVATE AI INFERENCE SYSTEMS

Architecture, Engineering, Optimization
and Production Deployment



DAVE HILMES

Building Small, Fast, Private AI Inference Systems

Architecture, Engineering, Optimization and Production Deployment

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Architecture, Engineering, Optimization and Production Deployment

This book is a practical, implementation-first guide to engineering local AI inference systems that are lightweight, low-latency, memory-efficient and genuinely private. If you need to deploy capable language models without cloud services, without leaking sensitive data, without unpredictable costs and with full control over the entire pipeline, this book shows you how to design, build, benchmark, secure and operate such systems in production. Every chapter is grounded in current technology, real measurements and working code you can run.

Introduction

The dominant narrative around artificial intelligence treats cloud APIs as inevitable. You send your prompt over the internet, a distant data center runs the computation and you get back tokens with a receipt. This is not always the right choice. It is not even the only choice anymore.

In the past three years, open-weight models have become genuinely capable at sizes small enough to run on a single machine, quantization methods have preserved most of their quality while cutting memory requirements by half or more and inference engines have been optimized to squeeze maximum performance from consumer hardware. The result is that small, private AI inference is no longer an experimental compromise. It is a practical engineering option with measurable trade-offs that you can reason about.

This book treats local inference as a serious engineering discipline. We start from first principles: what does it mean for a system to be small, fast and private and how do we measure those properties? We trace the complete inference lifecycle from model loading through token generation so you understand exactly what is happening when your code calls an LLM. We compare languages, frameworks, hardware options and optimization techniques with specific, current data rather than generalities. We build real systems: first a minimal inference application, then a configurable inference engine, then a production-grade HTTP API with streaming and structured outputs, then a retrieval-augmented generation pipeline and finally a security-hardened deployment architecture. Every implementation is complete and runnable.

The target reader is an engineer who knows how to build software and needs to deploy AI inference locally. You should be comfortable with command-line tools, basic systems administration and at least one programming language. Prior machine learning experience helps but is not required. If you are a data scientist who wants to understand how models actually run in production, or a security professional evaluating local inference for regulated environments, this book will give you the technical grounding you need.

A few principles guide every chapter:

- **Evidence over opinion:** Technology choices are justified with current documentation, benchmarks and explicit criteria, not brand loyalty or trends.
- **Implementation over abstraction:** Every concept is connected to working code or concrete configuration.
- **Trade-offs are explicit:** There is no universally best tool. Every choice sacrifices something. We make those sacrifices visible.
- **Privacy is foundational:** Security is not bolted on at the end. The threat model shapes the architecture from the start.

The book is organized in seven parts. Part I establishes the foundations: objectives, constraints, the inference lifecycle, model selection and language/runtime choices. Part II surveys the core technologies: inference frameworks, hardware backends and their relative strengths. Part III focuses on optimization: quantization, memory management, latency reduction and benchmarking methodology. Part IV walks through building increasingly capable systems with complete code. Part V covers security and privacy as architectural requirements. Part VI addresses deployment and lifecycle management. Part VII synthesizes the material into patterns, principles and a forward-looking assessment.

If you want to reach the working code quickly, you can jump to Chapter 11 and work through the implementations while using earlier chapters as reference. If you want to understand the technology landscape before committing to a stack, read Parts I and II first. Either way, the goal is the same: when you finish this book, you should be able to design, build and operate a small, fast, private AI inference system that you fully understand and can defend in front of your team.

Chapter 1: The Case for Small, Private AI

Defining the Design Space: What “Small” Means

In this book, “small” is not an absolute size. It is a relational property: small enough to fit in your memory budget, small enough to run on your target hardware, small enough to keep your latency within acceptable bounds and small enough to operate without external services when required.

For a consumer GPU with 12 GB of VRAM, “small” means models up to about 14 billion parameters at 4-bit quantization. For a high-end laptop with 32 GB of unified memory, “small” can mean 30-40 billion parameters if you are willing to accept slower speeds. For an edge device with 8 GB of RAM, “small” might be a 3-7 billion parameter model running entirely on CPU.

The parameter count alone is not the whole story. A model’s actual memory footprint depends on its precision (FP16, INT8, INT4 and so on), its architecture (dense versus mixture-of-experts) and its context length. A 7 billion parameter model in FP16 uses approximately 14 GB just for weights. At Q4_K_M quantization in GGUF format, the same model drops to about 4-4.5 GB. This is the difference between “I need an expensive GPU” and “I can run this on my laptop” [1, 2].

Speed matters too. A system that generates text at 2 tokens per second is technically “running locally” but practically unusable for interactive tasks. The book treats throughput as a first-class constraint: we want systems that are not just private but genuinely fast.

The Business and Technical Case for Local Inference

There are several compelling reasons to run AI inference locally rather than calling cloud APIs:

Data privacy and compliance. Some categories of data must not leave your network. Medical records under HIPAA, financial data under PCI DSS, personally identifiable information under GDPR, corporate intellectual property and national security information all create hard constraints. Even when regulations do not explicitly forbid sending data to a cloud provider, your customers or your legal team may not accept the risk. Local inference eliminates this risk entirely: the data never crosses your network boundary.

Predictable costs. Cloud inference pricing is usage-based. If your application gains popularity, your API bill scales with it. At low volumes this is convenient. At high volumes it becomes expensive and unpredictable. A local inference system has fixed infrastructure costs and essentially zero marginal cost per request. Once you have paid for the hardware, additional inference calls are “free” in terms of external charges. For high-throughput applications, the break-even point can come quickly.

Latency control. Sending prompts to a cloud API adds network latency. For applications where every millisecond counts, removing that round-trip can be decisive. Local inference also avoids queueing delays that occur when a provider’s servers are under heavy load. Your response time depends only on your hardware and your implementation.

Resilience and uptime. Cloud APIs can go down, return errors, or impose rate limits. If your application depends on inference, that dependency becomes a single point of failure. Local systems run under your control. If your server is up, inference works.

No vendor lock-in. Cloud APIs are proprietary. If the provider changes their pricing, deprecates a model, or modifies the API contract, you have no recourse. Open-weight models run locally are yours to deploy indefinitely, subject only to their licenses.

These advantages come at a cost. You must provision and maintain hardware. You are responsible for performance tuning, updates and security. The total cost of ownership can exceed cloud APIs for small workloads. The right choice depends on your specific requirements, which we formalize next.

Privacy, Security and Regulatory Drivers

The privacy case for local inference is often the strongest and most immediate driver. Consider the threat model of sending data to a cloud API:

- Your prompts and model responses traverse the public internet, encrypted but visible to anyone who can intercept the traffic.
- The provider's servers process your data. Depending on the provider's policies, that data may be logged, stored temporarily, or used for model improvement.
- The provider's employees, contractors, or attackers with compromised access could potentially see your data.
- The provider may be subject to legal process that compels data disclosure.

None of these risks are hypothetical. Data breaches, subpoena leaks and policy changes affecting training data have all occurred in the industry [3].

Local inference changes the threat model. The model weights and your data never leave your infrastructure. There is no third party that can see your prompts. The security boundary becomes your own infrastructure's perimeter, which you can design and audit.

This matters most in regulated domains:

- **Healthcare:** HIPAA and similar regulations restrict how protected health information can be transmitted and stored. Sending patient data to a cloud AI provider requires business associate agreements, risk assessments and ongoing compliance work. Local inference sidesteps much of this complexity.
- **Finance:** PCI DSS, SOX and other financial regulations impose strict requirements on data handling. Many financial institutions prohibit sending sensitive data to external services.
- **Government and defense:** Classified or sensitive government data often cannot leave air-gapped or strictly controlled networks.
- **Corporate IP:** Trade secrets, unreleased product designs, internal communications and source code may be valuable enough that even encrypted transmission to a vendor is unacceptable.

Beyond regulation, there is the simpler consideration of trust. Even when it is legally permissible to send data to a cloud provider, your customers may not be comfortable with it. Offering genuinely local inference can be a competitive advantage.

Measurable Success Criteria and Metrics

To treat small AI inference as engineering rather than marketing, we need measurable success criteria. The key metrics are:

- **Time to first token (TTFT):** The time from when a request arrives until the first output token is generated. For interactive chat, TTFT under 500 ms is ideal, under 1 second is acceptable and beyond 2 seconds feels sluggish. TTFT is dominated by the prefill phase, which processes the input prompt.
- **Inter-token latency (ITL):** The time between successive output tokens during generation. ITL determines the perceived fluency of the output. For chat, ITL under 100 ms feels natural. Above 300 ms, the output feels choppy. ITL is dominated by the decode phase, which is typically memory-bandwidth bound.
- **Throughput (tokens per second):** The total number of output tokens generated per second, across all concurrent requests. Throughput determines how many users a system can serve simultaneously.
- **Cold-start time:** The time to load a model from disk into memory when the system starts or when switching models. For user-facing applications, cold-start under 10 seconds is desirable. Longer waits are acceptable for batch workloads.
- **Peak resident memory:** The maximum amount of RAM or VRAM the system uses during operation. This determines hardware requirements.
- **Model loading overhead:** The memory and time required to load model weights. Memory-mapped loading can reduce RAM requirements at the cost of disk I/O latency.
- **Accuracy and quality:** Measured via perplexity on benchmark datasets, task-specific metrics, or subjective evaluation. Quantization and optimization must preserve acceptable quality.

These metrics are interdependent and often in tension. Optimizing for one can hurt another. Good engineering is about understanding these trade-offs and making conscious choices based on your priorities.

Fundamental Trade-offs: Quality versus Speed versus Size

The central tension in small AI systems is the quality-speed-size triangle. You can typically optimize for two at the expense of the third:

- **High quality + fast:** Requires a large model running on expensive hardware. A 70B parameter model on an H100 GPU generates excellent text at high speed but is not small or cheap.
- **High quality + small:** Requires a large model that is heavily quantized and runs slowly on modest hardware. A 70B model at Q2 quantization fits in 16 GB of RAM but generates text at barely usable speeds.
- **Fast + small:** Requires a smaller model that runs quickly on modest hardware but may lack sophistication. A 7B model at Q4_K_M on a consumer GPU generates text at interactive speeds with good but not exceptional quality.

The right balance depends on your use case. A customer service bot that needs to respond quickly to simple questions can tolerate lower quality. A research assistant analyzing technical documents may need higher quality even if responses take longer. A code generation tool needs both quality and reasonable speed.

Model selection is not a one-time decision. As smaller models improve and hardware becomes more capable, the trade-off frontier moves. A 7B model from 2023 is significantly less capable than a 7B model from 2025. You should periodically reassess your choices.

Beyond the basic triangle, there are secondary trade-offs:

- **Flexibility versus performance:** General-purpose models handle more tasks but use more memory than specialized models fine-tuned for a specific domain.
- **Context length versus memory:** Longer context windows enable richer interactions but increase KV cache memory usage linearly. A 128K context window can require as much memory as the model weights themselves [4].
- **Portability versus optimization:** Highly optimized solutions (TensorRT-LLM for NVIDIA GPUs) deliver peak performance on specific hardware but sacrifice cross-platform compatibility.

- **Ease of use versus control:** High-level tools like Ollama simplify deployment but limit fine-grained optimization.

When Small AI Is the Wrong Choice

Small, private AI inference is not universally superior. There are situations where cloud APIs are the better choice:

- **Low-volume experimentation:** If you are prototyping and making a few hundred requests per day, the cost of cloud APIs is trivial and the overhead of maintaining local infrastructure is not justified.
- **State-of-the-art requirements:** If your task requires the absolute best available model quality and you cannot work with the 5-15% quality degradation of smaller models, large cloud-hosted models may be necessary.
- **Multimodal complexity:** Image generation, high-resolution image understanding and video processing have higher hardware requirements that may make local deployment impractical.
- **Intermittent workloads:** If your inference needs are sporadic, paying for hardware that sits idle most of the time is economically inefficient. Cloud APIs charge only for what you use.
- **No ML engineering capacity:** If you have no one to set up, maintain and troubleshoot the infrastructure, a managed API service may be more reliable than a homegrown solution that breaks.

Understanding when local inference is the wrong choice is as important as understanding when it is right. The goal is not to replace cloud APIs everywhere but to use the right tool for each problem.

Chapter Summary

This chapter established the design space for small, private AI inference systems. We defined “small” as a relative property bounded by memory, speed and autonomy requirements. We surveyed the business, technical, privacy and regulatory motivations for local inference. We identified measurable success criteria that distinguish engineering from hype. We explored the

fundamental quality-speed-size trade-off that governs every design decision. And we clarified scenarios where cloud APIs remain the better choice.

The next chapter dives into the technical mechanics: a complete walk-through of what happens when a model generates text, from the moment a prompt arrives to the final output token.

Chapter 2: The Inference Lifecycle

Model Loading and Weight Deserialization

Before any text can be generated, the model must be loaded into memory. This is often the most time-consuming step in the inference lifecycle and determines your cold-start latency.

A language model is stored as a collection of tensors: multi-dimensional arrays of numbers representing learned weights, biases and normalization parameters. These tensors are serialized to disk in various formats: PyTorch checkpoint files (.bin or .pt), Hugging Face Safetensors (.safetensors), GGUF files for llama.cpp, or proprietary formats used by specific runtimes.

The loading process has three stages:

1. **Metadata parsing:** The file header contains model architecture information: number of layers, hidden dimension size, number of attention heads, vocabulary size and other hyperparameters. The loader reads this metadata to understand how to interpret the tensors.
2. **Tensor allocation:** Memory is allocated for each tensor according to its shape and data type. For a 7B parameter model in FP16, this means allocating approximately 14 GB of contiguous memory. Fragmented memory can cause allocation failures even when sufficient total memory exists.
3. **Data transfer:** The tensor data is read from disk and copied into allocated memory. This is I/O bound and depends on disk speed. SSDs typically deliver 500-700 MB/s for SATA and 3,000-7,000 MB/s for NVMe. Loading a 4 GB GGUF file from an NVMe SSD takes roughly 1 second of I/O time.

Modern inference engines use memory-mapped files (mmap) to optimize loading. Instead of copying the entire file into RAM, mmap maps the file directly into the process's virtual address space. The operating system loads pages on demand as they are accessed. This reduces RAM requirements and enables models larger than available memory to be loaded, at the cost of potential page faults and slower access [5].

When GPU acceleration is used, weights must be transferred from system RAM to GPU VRAM. This PCIe transfer adds latency: copying 14 GB over a PCIe 4.0 x16 link (32 GB/s theoretical) takes about 440 ms minimum. Some engines keep weights on the CPU and stream tensors as needed, trading transfer latency for reduced VRAM usage.

Tokenization: Encoding, Decoding and the Vocabulary

Language models do not operate on raw text. They work on tokens: integer IDs drawn from a vocabulary of fixed size. Tokenization converts text into token IDs for input and decoding converts output token IDs back into text.

Most modern models use subword tokenization with algorithms like Byte Pair Encoding (BPE) or SentencePiece. These algorithms start with a vocabulary of individual characters and iteratively merge the most frequent pairs, creating a vocabulary that efficiently represents common sequences while still handling rare and out-of-vocabulary words.

For example, the Llama 3 tokenizer has a vocabulary of about 128,000 tokens. The word “running” might be a single token, while “uncharacteristically” might be split into multiple tokens: “un”, “character”, “istically”. A typical English sentence of 20 words produces roughly 25-35 tokens.

Tokenization is not just splitting on spaces. It handles:

- **Punctuation and whitespace:** Tokens like “,” “.” and “ ” exist explicitly.
- **Special tokens:** Models define special tokens like (start of sequence), (end of sequence) and tokens used in chat templates like <|start_header_id|>, <|end_header_id|> and <|eot_id|>.
- **Unicode:** Tokenizers handle international characters and emojis, though non-English text typically uses more tokens per character than English.

The tokenizer is loaded along with the model. In GGUF files, the vocabulary and merge rules are embedded in the file. In Hugging Face formats, the tokenizer is a separate configuration. Tokenization itself is fast for typical prompts but can become noticeable for very long inputs.

Understanding tokenization matters for several reasons:

- **Prompt length limits:** A model's context window is specified in tokens, not characters or words. A "4,000 token limit" is roughly 3,000 English words.
- **Cost calculation:** Cloud APIs charge per token. Understanding tokenization helps estimate costs.
- **Performance:** Longer token sequences mean more computation during the prefill phase.

Prompt Construction and Template Engineering

Before tokenization, raw user input must be structured into a prompt that the model understands. This is where prompt construction and template engineering come in.

Modern chat models are trained with specific formatting conventions. The model expects messages to be wrapped in a chat template that distinguishes between system instructions, user messages and assistant responses. For example, Llama 3 uses a template like:

```
1 <|begin_of_text|><|start_header_id|>system<|end_header_id|>
2 You are a helpful assistant.<|eot_id|>
3 <|start_header_id|>user<|end_header_id|>
4 What is 2+2?<|eot_id|>
5 <|start_header_id|>assistant<|end_header_id|>
```

Each model family has its own template format. Using the wrong template can cause the model to generate garbled or incorrect responses. The template is not cosmetic: it shapes how the model interprets the input through patterns it learned during training.

Template engineering also involves:

- **System prompts:** Instructions that guide the model's behavior, such as "You are a coding assistant specialized in Python" or "Respond only in JSON format."
- **Few-shot examples:** Including example inputs and outputs in the prompt to guide the model's responses, especially for structured output tasks.
- **Context management:** In multi-turn conversations, maintaining the full conversation history within the context window.

Poor template engineering is one of the most common sources of “model not working correctly” issues. When debugging inference problems, always verify that the prompt template matches the model’s expected format.

Prefill: Processing the Input Context

Once the prompt is tokenized, the model enters the prefill phase. Prefill processes the entire input sequence and builds the internal state required for generation.

In a transformer model, prefill runs the full forward pass over all input tokens simultaneously. Self-attention layers compute relationships between all pairs of tokens: each token attends to every other token in the sequence. For a sequence of N tokens, this requires $O(N^2)$ operations in standard attention, though optimized implementations like FlashAttention reduce this to roughly $O(N)$ with a small constant factor.

The output of prefill is two sets of vectors for each token position:

- **Key vectors:** Represent what information each token contains.
- **Value vectors:** Represent what information each token contributes.

These key and value vectors are stored in a data structure called the KV cache, which is essential for the next phase.

Prefill is compute-bound: it performs a large amount of matrix multiplication and attention computation. Modern GPUs excel at this work because they can process thousands of elements in parallel. For a 1,000-token prompt, prefill on a capable GPU may take 100-500 ms depending on the model size.

Prefill dominates time-to-first-token (TTFT) because the user must wait for the entire input to be processed before any output begins. This is why applications with long inputs (such as summarizing documents) have higher initial latency.

Autoregressive Decoding and the Generation Loop

After prefill, the model enters the decode phase, where it generates output tokens one at a time. This is called autoregressive generation because each new token depends on all previous tokens.

The decode loop works as follows:

1. **Forward pass:** The model takes the most recent token as input and processes it through its layers. The self-attention mechanism attends to all previous tokens via the KV cache, avoiding recomputation of attention for the entire sequence.
2. **Logits computation:** The final layer produces logits: a vector of raw scores, one for each token in the vocabulary.
3. **Softmax:** The logits are converted to probabilities using the softmax function, producing a probability distribution over all possible next tokens.
4. **Sampling:** A token is selected from the distribution using a sampling strategy (discussed below).
5. **Output:** The selected token is added to the output and the KV cache is updated.
6. **Repeat:** Steps 1-5 continue until an end-of-sequence token is generated, a maximum length is reached, or the model is otherwise stopped.

This loop is fundamentally sequential: each token depends on the previous one, so tokens cannot be generated in parallel. This is the bottleneck that limits generation speed.

Unlike prefill, decode is memory-bandwidth bound. Each iteration only processes one new token, so the amount of computation is relatively small. However, the entire model's weights must be loaded from memory for each step. The limiting factor is how fast data can be moved from memory to the compute units, not how fast those units can compute.

For a 7B parameter model on a GPU with 1 TB/s memory bandwidth, theoretical maximum decode speed is about 70 tokens per second (1 TB/s divided by 14 GB of weights). Real-world speeds are lower due to overhead, typically 20-60 tokens per second depending on the hardware and optimization.

Attention Mechanisms and Key-Value Caching

The attention mechanism is the core computational pattern in transformer models. It allows each position in the sequence to attend to all other positions, capturing dependencies regardless of distance.

Self-attention works by projecting each token into three vectors: query (Q), key (K) and value (V). For each position, the query is compared to all keys

using a dot product, scaled and softmaxed to produce attention weights. These weights are used to compute a weighted sum of the values, producing the output for that position.

The KV cache avoids recomputing keys and values for every token at every step. After prefill, keys and values for all input tokens are stored. During decode, only the new token's Q, K and V are computed. The attention operation then uses the new query with all stored keys (including the new one) and all stored values.

The KV cache grows linearly with sequence length. Its memory usage is calculated as:

$$\begin{aligned} 1 \quad \text{KV cache (bytes)} &= \text{batch_size} \times \text{context_length} \times 2 \times \text{num_layers} \times \text{num_kv_heads} \\ &\rightarrow \times \text{head_dim} \times \text{bytes_per_element} \end{aligned}$$

For Llama 3.1 8B (32 layers, 8 attention heads, 128-dim heads) at 128K context in FP16, the KV cache requires approximately 16 GB of VRAM, which can exceed the memory needed for the model weights [6]. This is why long-context models are memory-intensive even when quantized.

KV cache optimization techniques include:

- **Quantized KV cache:** Storing keys and values at lower precision (Q8, Q4) to reduce memory.
- **Paged attention (vLLM):** Treating the KV cache as paged virtual memory to eliminate fragmentation [7].
- **Sliding window attention:** Only caching a fixed window of recent tokens (used by Mistral 7B).
- **Prefix caching:** Reusing KV cache entries for common prompt prefixes across requests.
- **Token eviction:** Discarding older tokens when the cache is full.

Sampling Strategies and Probability Distributions

The model outputs a probability distribution over the vocabulary at each step. How we select the next token from this distribution shapes the output's character and quality.

Common sampling strategies:

- **Greedy decoding:** Always select the token with the highest probability. Produces deterministic, often coherent output but can be repetitive and miss interesting alternatives. Useful for extraction and translation tasks.
- **Random sampling:** Select tokens proportional to their probabilities. Produces more diverse output but can generate low-quality text if probabilities are noisy. Controlled by the temperature parameter: higher temperature flattens the distribution (more random), lower temperature sharpens it (more focused on high-probability tokens).
- **Top-K sampling:** Restrict sampling to the K most probable tokens, then sample proportionally from those. Prevents the model from selecting very unlikely tokens that would produce nonsense. Typical K values range from 10 to 100.
- **Top-p (nucleus) sampling:** Select the smallest set of tokens whose cumulative probability exceeds p (typically 0.9 or 0.95), then sample proportionally from that set. Adapts the effective vocabulary size based on how peaked the distribution is. Generally preferred over top-K for its adaptability.
- **Min-p sampling:** A newer strategy that filters tokens below a minimum probability threshold relative to the most probable token. Provides more consistent quality than top-p in some cases.
- **Repetition penalties:** Techniques to reduce repetition, such as scaling down the probability of recently used tokens. Important for longer generations where models can get stuck in loops.

Production systems typically expose these parameters through their API so applications can tune generation behavior for different tasks. Creative writing might use temperature 0.8 with top-p 0.95. Code generation might use temperature 0.2 with top-p 0.9 for more deterministic output.

Streaming, Batching and Concurrency

Real-world inference systems must handle multiple requests efficiently. Three techniques address this: streaming, batching and concurrency.

Streaming sends output tokens to the client as they are generated, rather than waiting for the entire response. This reduces perceived latency: the user sees the first token immediately instead of waiting for a 1,000-token response

to complete. Streaming is typically implemented using Server-Sent Events (SSE) for HTTP or similar protocols.

Batching processes multiple requests together in a single forward pass, improving throughput by amortizing overhead. Static batching groups a fixed number of requests and processes them together, but it is inefficient because requests with short outputs sit idle waiting for longer ones to complete.

Continuous batching (dynamic batching) is more sophisticated: requests are added to and removed from the batch as they complete. When one request finishes generating, the next queued request takes its place. vLLM pioneered this approach for LLM serving, achieving up to 24x throughput improvement over static batching on production workloads [8].

Concurrency at the application level involves handling multiple client connections, managing request queues and scheduling work on available compute resources. A well-designed system separates the request handling layer (accepting HTTP connections, validating input) from the inference layer (running the model), using queues and worker pools to prevent overload.

These techniques interact in complex ways. Batching increases throughput but can increase individual request latency. Streaming improves perceived latency but complicates error handling and output validation. Production systems must balance these factors based on their workload characteristics.

Chapter Summary

This chapter walked through the complete inference lifecycle. We saw how models are loaded from disk into memory, how text is tokenized into numeric sequences, how prompts are structured with chat templates, how prefill processes input tokens in parallel, how autoregressive decode generates output tokens sequentially, how the KV cache enables efficient attention, how sampling strategies shape output quality and how streaming, batching and concurrency serve real-world workloads.

Understanding this lifecycle is essential for making informed decisions about optimization and architecture. Every performance technique discussed in later chapters targets specific stages of this pipeline. Every security consideration relates to data flowing through it. Every design choice ultimately affects how the system loads models, processes prompts and generates tokens.

The next chapter turns to model selection: how to choose the right model for your constraints and requirements.

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