

Chinchilla Scaling Laws - Code Demonstration

Training Compute-Optimal Large Language Models

This notebook demonstrates the key scaling relationships discovered in the Chinchilla paper.

 Open in Colab

```
In [ ]: # Install required packages
!pip install numpy matplotlib scipy pandas seaborn
```

```
In [1]: import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from scipy.optimize import minimize
import pandas as pd

# Set style
sns.set_style("whitegrid")
plt.rcParams['figure.figsize'] = (12, 8)
plt.rcParams['font.size'] = 12
```

1. The Parametric Loss Function

Chinchilla models loss as:

$$L(N, D) = E + \frac{A}{N^\alpha} + \frac{B}{D^\beta}$$

Where:

- N = number of parameters
- D = number of training tokens
- E = irreducible loss (entropy of natural text)
- α, β = scaling exponents

```
In [2]: # Chinchilla's fitted parameters
E = 1.69
A = 406.4
B = 410.7
alpha = 0.34
beta = 0.28

def loss_function(N, D):
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"""Compute predicted loss given model size N and training tokens D"""
return E + A / (N ** alpha) + B / (D ** beta)

# Example: Compute loss for different model/data configurations
print("Loss predictions:")
print(f"Gopher (280B params, 300B tokens): {loss_function(280e9, 300e9):.4f}")
print(f"Chinchilla (70B params, 1.4T tokens): {loss_function(70e9, 1.4e12):.4f}")
print(f"GPT-3 (175B params, 300B tokens): {loss_function(175e9, 300e9):.4f}"
```

Loss predictions:

Gopher (280B params, 300B tokens): 1.9933
 Chinchilla (70B params, 1.4T tokens): 1.9366
 GPT-3 (175B params, 300B tokens): 2.0023

2. Optimal Scaling Relationships

For a given compute budget C , the optimal model size and training tokens are:

$$N_{opt} \propto C^{0.50}$$

$$D_{opt} \propto C^{0.49}$$

```
In [3]: def compute_flops(N, D):
    """Approximate FLOPs for training (simplified)"""
    return 6 * N * D

def optimal_model_size(C, a=0.50, G=0.5):
    """Compute optimal model size for compute budget C"""
    return G * (C / 6) ** a

def optimal_tokens(C, b=0.49, H=2.0):
    """Compute optimal training tokens for compute budget C"""
    return H * (C / 6) ** b

# Generate compute budgets from 1e20 to 1e25 FLOPs
compute_budgets = np.logspace(20, 25, 50)

# Compute optimal allocations
optimal_params = [optimal_model_size(C) for C in compute_budgets]
optimal_data = [optimal_tokens(C) for C in compute_budgets]

# Create comparison dataframe
models_df = pd.DataFrame({
    'Model': ['GPT-3', 'Gopher', 'Chinchilla', 'MT-NLG'],
    'Parameters': [175e9, 280e9, 70e9, 530e9],
    'Tokens': [300e9, 300e9, 1.4e12, 270e9],
    'Compute': [175e9*300e9*6, 280e9*300e9*6, 70e9*1.4e12*6, 530e9*270e9*6]
})

print("\nExisting Large Models:")
print(models_df.to_string(index=False))
```

Existing Large Models:

Model	Parameters	Tokens	Compute
GPT-3	1.750000e+11	3.000000e+11	3.150000e+23
Gopher	2.800000e+11	3.000000e+11	5.040000e+23
Chinchilla	7.000000e+10	1.400000e+12	5.880000e+23
MT-NLG	5.300000e+11	2.700000e+11	8.586000e+23

3. Visualizing Chinchilla vs Kaplan Scaling

```
In [4]: # Kaplan et al. (2020) scaling laws
def kaplan_model_size(C, a=0.73):
    return 0.5 * (C / 6) ** a

def kaplan_tokens(C, b=0.27):
    return 2.0 * (C / 6) ** b

# Compute Kaplan predictions
kaplan_params = [kaplan_model_size(C) for C in compute_budgets]
kaplan_data = [kaplan_tokens(C) for C in compute_budgets]

# Create figure with two subplots
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(16, 6))

# Plot 1: Optimal Parameters vs Compute
ax1.loglog(compute_budgets, optimal_params, 'b-', linewidth=2, label='Chinchilla')
ax1.loglog(compute_budgets, kaplan_params, 'r--', linewidth=2, label='Kaplan')

# Add existing models
ax1.scatter(models_df['Compute'], models_df['Parameters'],
            c=['red', 'orange', 'green', 'purple'], s=200, zorder=5, edgecolor='black')
for idx, row in models_df.iterrows():
    ax1.annotate(row['Model'], (row['Compute'], row['Parameters']),
                xytext=(10, 10), textcoords='offset points', fontsize=10)

ax1.set_xlabel('Training FLOPs', fontsize=14)
ax1.set_ylabel('Optimal Model Size (Parameters)', fontsize=14)
ax1.set_title('Optimal Model Size vs Compute Budget', fontsize=16)
ax1.legend(fontsize=12)
ax1.grid(True, alpha=0.3)

# Plot 2: Optimal Tokens vs Compute
ax2.loglog(compute_budgets, optimal_data, 'b-', linewidth=2, label='Chinchilla')
ax2.loglog(compute_budgets, kaplan_data, 'r--', linewidth=2, label='Kaplan')

# Add existing models
ax2.scatter(models_df['Compute'], models_df['Tokens'],
            c=['red', 'orange', 'green', 'purple'], s=200, zorder=5, edgecolor='black')
for idx, row in models_df.iterrows():
    ax2.annotate(row['Model'], (row['Compute'], row['Tokens']),
                xytext=(10, 10), textcoords='offset points', fontsize=10)

ax2.set_xlabel('Training FLOPs', fontsize=14)
ax2.set_ylabel('Optimal Training Tokens', fontsize=14)
ax2.set_title('Optimal Training Tokens vs Compute Budget', fontsize=16)
ax2.legend(fontsize=12)
```

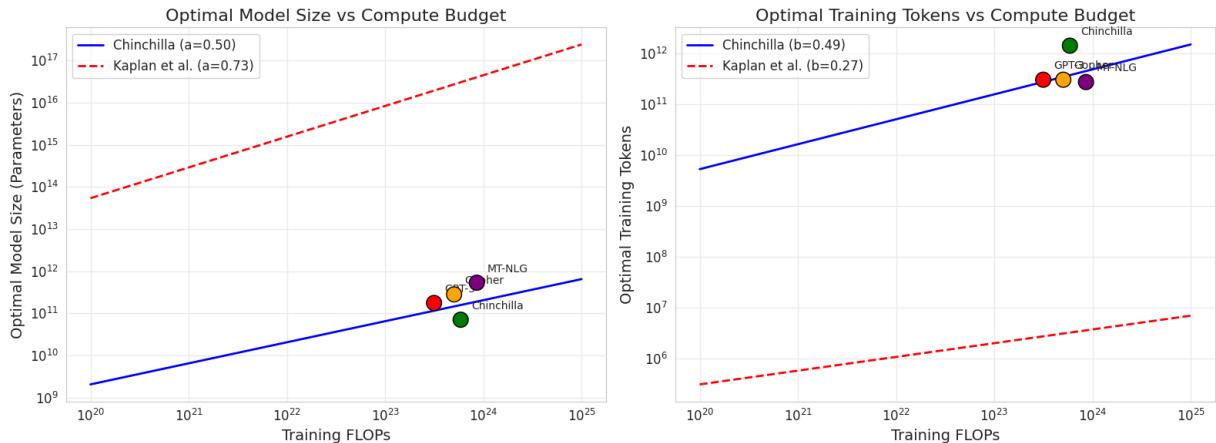
```

ax2.grid(True, alpha=0.3)

plt.tight_layout()
plt.show()

print("\n\n Key Insight: Chinchilla predicts balanced scaling (50/50), while

```



Key Insight: Chinchilla predicts balanced scaling (50/50), while Kaplan heavily favored model size (73/27)

4. Loss Contour Visualization

```

In [5]: # Create a grid of model sizes and token counts
N_range = np.logspace(8, 12, 100) # 100M to 1T parameters
D_range = np.logspace(10, 13, 100) # 10B to 10T tokens
N_grid, D_grid = np.meshgrid(N_range, D_range)

# Compute loss for each point
L_grid = loss_function(N_grid, D_grid)

# Create figure
plt.figure(figsize=(12, 8))
levels = np.linspace(1.8, 3.0, 25)
contour = plt.contour(N_grid, D_grid, L_grid, levels=levels, cmap='viridis')
plt.clabel(contour, inline=True, fontsize=8, fmt='%.2f')

# Plot efficient frontier (iso-FLOP lines)
for C in [1e22, 1e23, 5.76e23, 1e24, 1e25]:
    N_opt = optimal_model_size(C)
    D_opt = optimal_tokens(C)
    plt.scatter([N_opt], [D_opt], c='red', s=100, zorder=5, edgecolor='white')

# Draw iso-FLOP line
N_isoflop = np.logspace(8, 12, 50)
D_isoflop = C / (6 * N_isoflop)
plt.plot(N_isoflop, D_isoflop, 'r--', alpha=0.5, linewidth=1)

# Add existing models
for idx, row in models_df.iterrows():
    plt.scatter([row['Parameters']], [row['Tokens']], s=300, zorder=6, edgecolor='black', linewidth=2)
    plt.annotate(row['Model'], (row['Parameters'], row['Tokens']),)

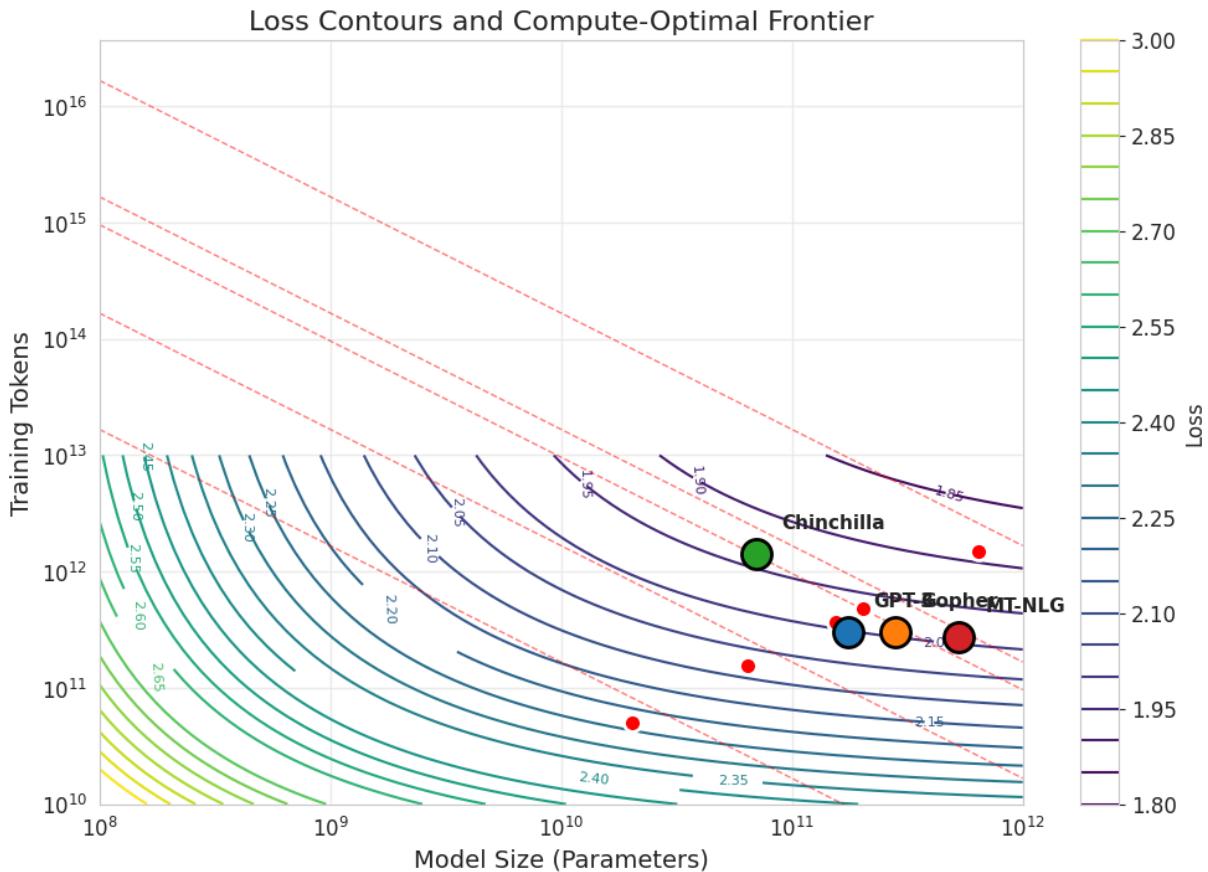
```

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xytext=(15, 15), textcoords='offset points', fontsize=11, fc
plt.xscale('log')
plt.yscale('log')
plt.xlabel('Model Size (Parameters)', fontsize=14)
plt.ylabel('Training Tokens', fontsize=14)
plt.title('Loss Contours and Compute–Optimal Frontier', fontsize=16)
plt.colorbar(contour, label='Loss')
plt.grid(True, alpha=0.3)
plt.show()

print("\n\n Red dots show the compute-optimal frontier. Existing models are

```



Red dots show the compute-optimal frontier. Existing models are undertrained!

5. Practical Calculator: Given Your Compute Budget

In [6]:

```

def recommend_model_config(compute_budget_flops):
    """
    Given a compute budget in FLOPs, recommend optimal model size and training tokens.
    """
    N_opt = optimal_model_size(compute_budget_flops)
    D_opt = optimal_tokens(compute_budget_flops)
    predicted_loss = loss_function(N_opt, D_opt)

    print(f"=60")
    print(f"Compute Budget: {compute_budget_flops:.2e} FLOPs")
    print(f"=60")

```

```

print(f"Optimal Model Size: {N_opt/1e9:.2f}B parameters")
print(f"Optimal Training Tokens: {D_opt/1e9:.2f}B tokens")
print(f"Predicted Loss: {predicted_loss:.4f}")
print(f"=*60)

# Compare to Kaplan
N_kaplan = kaplan_model_size(compute_budget_flops)
D_kaplan = kaplan_tokens(compute_budget_flops)

print(f"\nKaplan et al. (2020) would recommend:")
print(f" Model Size: {N_kaplan/1e9:.2f}B parameters ({N_kaplan/N_opt:.2f}x larger")
print(f" Training Tokens: {D_kaplan/1e9:.2f}B tokens ({D_opt/D_kaplan:.2f}x more data needed!")

return N_opt, D_opt

# Example: What if you have the same budget as Gopher?
gopher_compute = 5.76e23
recommend_model_config(gopher_compute)

print("\n" + "=*60)
print("TRY IT YOURSELF: Change the compute budget below!")
print("=*60)

# Interactive: Try different budgets
my_compute_budget = 1e24 # Change this value!
recommend_model_config(my_compute_budget)

```

```
=====
Compute Budget: 5.76e+23 FLOPs
=====
Optimal Model Size: 154.92B parameters
Optimal Training Tokens: 365.04B tokens
Predicted Loss: 1.9914
=====
```

```
Kaplan et al. (2020) would recommend:
 Model Size: 29924575.92B parameters (193162.31x larger)
 Training Tokens: 0.00B tokens (113788.84x more data needed!)

=====
```

```
TRY IT YOURSELF: Change the compute budget below!
=====

Compute Budget: 1.00e+24 FLOPs
=====
Optimal Model Size: 204.12B parameters
Optimal Training Tokens: 478.34B tokens
Predicted Loss: 1.9684
=====
```

```
Kaplan et al. (2020) would recommend:
 Model Size: 44763041.89B parameters (219293.22x larger)
 Training Tokens: 0.00B tokens (128471.48x more data needed!)

=====
```

Out[6]: (204124145231.93152, 478339101004.36536)

6. Token-to-Parameter Ratio Analysis

```
In [7]: # Compare token-to-parameter ratios
models_comparison = pd.DataFrame({
    'Model': ['GPT-3', 'Gopher', 'Chinchilla', 'LLaMA-1 (65B)', 'LLaMA-2 (70B)', 'LLaMA-3 (8B)'],
    'Parameters (B)': [175, 280, 70, 65, 70, 8],
    'Tokens (B)': [300, 300, 1400, 1400, 2000, 15000],
})

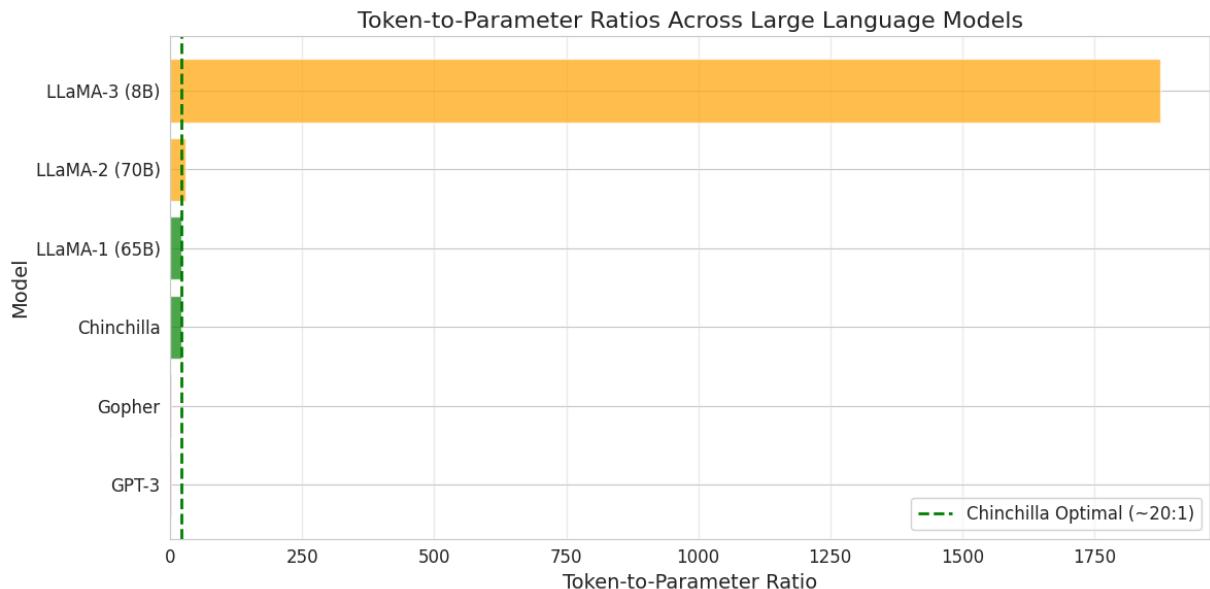
models_comparison['Token:Param Ratio'] = models_comparison['Tokens (B)'] / models_comparison['Parameters (B)']
models_comparison['Chinchilla Optimal?'] = models_comparison['Token:Param Ratio'].apply(lambda x: '✓ Optimal' if 15 <= x <= 25 else ('⚠ Overtrained' if x > 25 else '✗ Undertrained'))
print("\nToken-to-Parameter Ratio Comparison:")
print(models_comparison.to_string(index=False))

# Visualize
plt.figure(figsize=(12, 6))
colors = ['red' if '✗' in status else 'orange' if '⚠' in status else 'green' for status in models_comparison['Chinchilla Optimal?']]

plt.barh(models_comparison['Model'], models_comparison['Token:Param Ratio'], color=colors)
plt.axvline(x=20, color='green', linestyle='--', linewidth=2, label='Chinchilla Optimal')
plt.xlabel('Token-to-Parameter Ratio', fontsize=14)
plt.ylabel('Model', fontsize=14)
plt.title('Token-to-Parameter Ratios Across Large Language Models', fontsize=16)
plt.legend(fontsize=12)
plt.grid(axis='x', alpha=0.3)
plt.tight_layout()
plt.show()
```

Token-to-Parameter Ratio Comparison:

Model	Parameters (B)	Tokens (B)	Token:Param Ratio	Chinchilla Optimal?
GPT-3	175	300	1.714286	✗ Undertrained
Gopher	280	300	1.071429	✗ Undertrained
Chinchilla	70	1400	20.000000	✓ Optimal
LLaMA-1 (65B)	65	1400	21.538462	✓ Optimal
LLaMA-2 (70B)	70	2000	28.571429	⚠ Overtrained
LLaMA-3 (8B)	8	15000	1875.000000	⚠ Overtrained



7. Key Takeaways

The Chinchilla Scaling Law:

1. **Equal scaling:** For every doubling of compute, double BOTH model size and training tokens
2. **Previous models were undertrained:** GPT-3, Gopher, etc. used $\sim 4\times$ too many parameters and $\sim 4\times$ too little data
3. **Practical impact:**
 - Same compute budget \rightarrow Better performance with smaller, longer-trained models
 - $4\times$ reduction in inference costs
 - Much more emphasis on data quality and quantity

Implications:

- **Training:** Spend more time collecting and curating data
- **Deployment:** Smaller models are cheaper to serve
- **Research:** Data scaling is as important as model scaling