SNN_Conversion.ipynb

In [2]:

```
# %%
import os
from pathlib import Path

import torch
import torch.nn as nn
import torch.nn.functional as F

import torchaudio
import torchaudio.transforms as T

import numpy as np
import pandas as pd
from torch.utils.data import Dataset, DataLoader
from tqdm import tqdm
import matplotlib.pyplot as plt

import snntorch as snn
from snntorch import surrogate

# For audio loading without torchcodec
import soundfile as sf


# -------------------------------
# FIXED: Project root = parent of this folder
# -------------------------------
CURRENT_DIR = Path.cwd()
PROJECT_ROOT = CURRENT_DIR.parent               # <---- FIXED
DATA_ROOT = PROJECT_ROOT / "sample_data" / "speech_commands_v0.02"
MODEL_DIR = PROJECT_ROOT / "saved_models"

print("Notebook directory:", CURRENT_DIR)
print("PROJECT_ROOT:", PROJECT_ROOT)
print("DATA_ROOT exists:", DATA_ROOT.exists())
print("MODEL_DIR exists:", MODEL_DIR.exists())

device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
print("Using device:", device)
```

```
Notebook directory: /Users/maddy/Desktop/PLEP/Project/CS-576-Final-Proj
ect/snn_conversion
PROJECT_ROOT: /Users/maddy/Desktop/PLEP/Project/CS-576-Final-Project
DATA_ROOT exists: True
MODEL_DIR exists: True
Using device: cpu
```

In [3]:
```
# %%
# Keywords (same as baseline CNN)
CLASSES = ["yes", "no", "go", "stop", "down", "up"]

SAMPLE_RATE = 16000
N_MFCC = 40

# MFCC transform (same configuration as training)
mfcc_transform = T.MFCC(
    sample_rate=SAMPLE_RATE,
    n_mfcc=N_MFCC,
    melkwargs={
        "n_fft": 400,
        "hop_length": 160,
        "n_mels": 40,
        "center": False,
    },
)

def wav_to_mfcc(path: Path) -> torch.Tensor:
    """
    Load WAV file using soundfile + compute MFCCs.
    Returns tensor [40, T].
    """
    # soundfile returns (samples, sr)
    waveform, sr = sf.read(str(path))
    waveform = torch.tensor(waveform).float().unsqueeze(0)  # [1, N]

    if sr != SAMPLE_RATE:
        waveform = torchaudio.functional.resample(waveform, sr, SAMPLE

    mfcc = mfcc_transform(waveform).squeeze(0)  # [40, T]

    # per-sample normalization (same style as training)
    mfcc = (mfcc - mfcc.mean()) / (mfcc.std() + 1e-6)
    mfcc = torch.clamp(mfcc, -2.0, 2.0)
    return mfcc
```

In [4]:
```
# %%
# Helpers to read the official val/test splits
val_list_path = DATA_ROOT / "validation_list.txt"
test_list_path = DATA_ROOT / "testing_list.txt"

def read_split_list(path: Path):
    with open(path, "r") as f:
        return [line.strip() for line in f.readlines()]

val_rel = set(read_split_list(val_list_path))
test_rel = set(read_split_list(test_list_path))

def make_file_lists(data_root: Path, classes):
    train_files, val_files, test_files = [], [], []
```

```
    for cls in classes:
        cls_dir = data_root / cls
        if not cls_dir.exists():
            continue
        for wav_path in cls_dir.glob("*.wav"):
            rel = f"{cls}/{wav_path.name}"
            if rel in val_rel:
                val_files.append(wav_path)
            elif rel in test_rel:
                test_files.append(wav_path)
            else:
                train_files.append(wav_path)

    return train_files, val_files, test_files

train_files, val_files, test_files = make_file_lists(DATA_ROOT, CLASSE

print(f"Train files: {len(train_files)}")
print(f"Val files:   {len(val_files)}")
print(f"Test files:  {len(test_files)}")
```

```
Train files: 18657
Val files:   2252
Test files:  2468
```

In [5]:

```
# %%
class KWS_Dataset(Dataset):
    def __init__(self, file_list, classes):
        self.files = file_list
        self.classes = classes

    def __len__(self):
        return len(self.files)

    def __getitem__(self, idx):
        path = self.files[idx]
        mfcc = wav_to_mfcc(path)  # [40, T]
        label_name = path.parent.name
        y = self.classes.index(label_name)
        return mfcc, y

def pad_collate(batch):
    xs, ys = zip(*batch)
    max_t = max(x.shape[1] for x in xs)
    xs = [F.pad(x, (0, max_t - x.shape[1])) for x in xs]
    xs = torch.stack(xs)  # [B,40,T]
    ys = torch.tensor(ys)
    return xs, ys

BATCH_SIZE = 128

train_dataset = KWS_Dataset(train_files, CLASSES)
```

```
val_dataset   = KWS_Dataset(val_files, CLASSES)
test_dataset  = KWS_Dataset(test_files, CLASSES)

train_loader = DataLoader(train_dataset, batch_size=BATCH_SIZE, shuffl
                          collate_fn=pad_collate, num_workers=0)
val_loader   = DataLoader(val_dataset, batch_size=BATCH_SIZE, shuffle=
                          collate_fn=pad_collate, num_workers=0)
test_loader  = DataLoader(test_dataset, batch_size=BATCH_SIZE, shuffle
                          collate_fn=pad_collate, num_workers=0)

print("Train:", len(train_dataset), "| Val:", len(val_dataset), "| Tes
```

```
Train: 18657 | Val: 2252 | Test: 2468
```

In [11]:

```
class CNN_KWS(nn.Module):
    def __init__(self, num_classes=6, flatten_dim=3840):
        super().__init__()

        self.flatten_dim = flatten_dim

        self.features = nn.Sequential(
            nn.Conv2d(1, 8, kernel_size=5, stride=1, padding=2),
            nn.ReLU(),
            nn.MaxPool2d(2),
            nn.Conv2d(8, 16, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(2),
        )

        self.classifier = nn.Sequential(
            nn.Linear(self.flatten_dim, 64),
            nn.ReLU(),
            nn.Linear(64, num_classes),
        )

    def forward(self, x):
        x = x.unsqueeze(1)           # [B,1,40,T]
        x = self.features(x)
        x = torch.flatten(x, 1)      # [B, F]

        F = x.shape[1]

        # 👇 CRITICAL: match checkpoint’s expected flatten_dim (3840)
        if F > self.flatten_dim:
            x = x[:, :self.flatten_dim]
        elif F < self.flatten_dim:
            pad = self.flatten_dim - F
            x = F.pad(x, (0, pad))  # pad at end

        return self.classifier(x)
```

In [13]:

```
cnn_ckpt_path = MODEL_DIR / "baseline_cnn_kws_vfinal.pt"
```

```
print("CNN checkpoint exists:", cnn_ckpt_path.exists())

# Load checkpoint just to get flatten_dim
state_dict = torch.load(cnn_ckpt_path, map_location=device)
flatten_dim_ckpt = state_dict["classifier.0.weight"].shape[1]
print("Flatten dim in checkpoint =", flatten_dim_ckpt)

# Build CNN using correct flatten_dim
cnn_model = CNN_KWS(num_classes=6, flatten_dim=flatten_dim_ckpt).to(de

# Load weights
cnn_model.load_state_dict(state_dict)
cnn_model.eval()

print("CNN loaded successfully.")
```

```
CNN checkpoint exists: True
Flatten dim in checkpoint = 3840
CNN loaded successfully.
```

In [14]:
```
# %%
@torch.no_grad()
def eval_cnn(loader, model, device=device):
    model.eval()
    correct = 0
    total = 0
    for mfcc, y in tqdm(loader, desc="Eval CNN"):
        mfcc, y = mfcc.to(device), y.to(device)
        logits = model(mfcc)
        preds = logits.argmax(dim=1)
        correct += (preds == y).sum().item()
        total += y.numel()
    return correct / total

val_acc_cnn = eval_cnn(val_loader, cnn_model, device)
test_acc_cnn = eval_cnn(test_loader, cnn_model, device)

print(f"CNN VAL  Accuracy: {val_acc_cnn*100:.2f}%")
print(f"CNN TEST Accuracy: {test_acc_cnn*100:.2f}%")
```

```
Eval CNN: 100%|████████████████████████████████████████████████████████
█████████████████| 18/18 [00:01<00:00, 15.42it/s]
Eval CNN: 100%|████████████████████████████████████████████████████████
█████████████████| 20/20 [00:01<00:00, 14.90it/s]
CNN VAL  Accuracy: 81.79%
CNN TEST Accuracy: 80.43%
```

In [15]:
```
# %%
spike_grad = surrogate.fast_sigmoid()

class SNN_KWS(nn.Module):
    def __init__(self, base_cnn: CNN_KWS, num_steps: int = 50, beta: f
        super().__init__()
```

```
        self.num_steps = num_steps
        self.features = base_cnn.features
        self.fc1 = base_cnn.classifier[0]  # LazyLinear/Linear -> 64
        self.fc2 = base_cnn.classifier[2]  # Linear 64 -> num_classes

        self.lif1 = snn.Leaky(beta=beta, spike_grad=spike_grad)
        self.lif2 = snn.Leaky(beta=beta, spike_grad=spike_grad)

    def forward(self, x):
        """
        x: [B,40,T]
        Returns: [T,B,num_classes] spike tensor.
        """
        spk2_rec = []
        mem1 = self.lif1.init_leaky()
        mem2 = self.lif2.init_leaky()

        # encode static MFCC as constant input across time
        x = x.unsqueeze(1)  # [B,1,40,T]

        for _ in range(self.num_steps):
            cur = self.features(x)        # [B,C,H,W]
            cur = torch.flatten(cur, 1)   # [B,F]
            cur = F.relu(self.fc1(cur))   # [B,64]
            spk1, mem1 = self.lif1(cur, mem1)
            cur2 = self.fc2(spk1)         # [B,num_classes]
            spk2, mem2 = self.lif2(cur2, mem2)
            spk2_rec.append(spk2)

        return torch.stack(spk2_rec)  # [T,B,num_classes]
```

In [16]:

```
# %%
@torch.no_grad()
def eval_snn_energy(loader, snn_model, T: int, device=device):
    """
    Evaluate SNN accuracy, spike activity, and a simple energy proxy.

    Returns:
        accuracy
        avg_spike_rate
        energy_score
        efficiency = accuracy / energy_score
    """
    snn_model.eval()
    total = 0
    correct = 0
    total_spikes = 0.0
    total_neurons = 0
    bad_batches = 0

    for mfcc, y in tqdm(loader, desc=f"SNN Eval @T={T}"):
        try:
```

```
            mfcc, y = mfcc.to(device), y.to(device)
            out_TBC = snn_model(mfcc)        # [T,B,C]

            # spike counts
            spikes = (out_TBC > 0).float().sum().item()
            total_spikes += spikes
            total_neurons += out_TBC.numel()

            # temporal accumulation -> logits
            logits = out_TBC.sum(dim=0)      # [B,C]
            preds = logits.argmax(dim=1)
            correct += (preds == y).sum().item()
            total += y.numel()

        except Exception as e:
            bad_batches += 1
            print(f"Skipped batch: {e}")
            continue

    accuracy = correct / max(total, 1)
    avg_spike_rate = total_spikes / max(total_neurons, 1)
    energy_score = avg_spike_rate * T
    efficiency = accuracy / (energy_score + 1e-8)

    print(f"\nSkipped {bad_batches} problematic batches.")
    print(
        f"Acc={accuracy*100:.2f}% | "
        f"SpikeRate={avg_spike_rate:.6f} | "
        f"Energy={energy_score:.4f} | "
        f"Eff={efficiency:.6f}"
    )

    return accuracy, avg_spike_rate, energy_score, efficiency
```

In [17]:

```
# %%
beta_values = [0.90, 0.95, 0.97, 0.99]
T_values = [10, 25, 50, 75, 100]

results = []

for beta in beta_values:
    print(f"\n===== β = {beta} =====")
    snn_model = SNN_KWS(cnn_model, num_steps=max(T_values), beta=beta)

    for T in T_values:
        print(f"\n--- Evaluating T={T} on VAL ---")
        val_acc, val_rate, val_energy, val_eff = eval_snn_energy(
            val_loader, snn_model, T=T, device=device
        )

        print(f"\n--- Evaluating T={T} on TEST ---")
        test_acc, test_rate, test_energy, test_eff = eval_snn_energy(
```

```
                test_loader, snn_model, T=T, device=device
            )

            results.append({
                "model": "SNN",
                "beta": beta,
                "T": T,
                "val_acc": val_acc * 100,
                "test_acc": test_acc * 100,
                "avg_spike_rate": test_rate,
                "energy_proxy": test_energy,
                "efficiency": test_eff,
            })

# Add CNN baseline row
results.append({
    "model": "CNN",
    "beta": "-",
    "T": "-",
    "val_acc": val_acc_cnn * 100,
    "test_acc": test_acc_cnn * 100,
    "avg_spike_rate": 0.0,
    "energy_proxy": 1.0,    # baseline energy = 1x
    "efficiency": test_acc_cnn * 100 / 1.0,
})

df = pd.DataFrame(results)
display(df.sort_values(by=["model", "beta", "T"], key=lambda col: col.
```

```
===== β = 0.9 =====

--- Evaluating T=10 on VAL ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████████████████| 18/18 [00:24<00:00,  1.37s/it]
Skipped 0 problematic batches.
Acc=50.75% | SpikeRate=0.067156 | Energy=0.6716 | Eff=0.755777

--- Evaluating T=10 on TEST ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████████████████| 20/20 [00:27<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=49.96% | SpikeRate=0.069352 | Energy=0.6935 | Eff=0.720379

--- Evaluating T=25 on VAL ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████████████████| 18/18 [00:23<00:00,  1.33s/it]
Skipped 0 problematic batches.
Acc=50.75% | SpikeRate=0.067156 | Energy=1.6789 | Eff=0.302311

--- Evaluating T=25 on TEST ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████████████████| 20/20 [00:26<00:00,  1.31s/it]
```

```
Skipped 0 problematic batches.
Acc=49.96% | SpikeRate=0.069352 | Energy=1.7338 | Eff=0.288151

--- Evaluating T=50 on VAL ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:23<00:00,  1.33s/it]
Skipped 0 problematic batches.
Acc=50.75% | SpikeRate=0.067156 | Energy=3.3578 | Eff=0.151155

--- Evaluating T=50 on TEST ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=49.96% | SpikeRate=0.069352 | Energy=3.4676 | Eff=0.144076

--- Evaluating T=75 on VAL ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=50.75% | SpikeRate=0.067156 | Energy=5.0367 | Eff=0.100770

--- Evaluating T=75 on TEST ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=49.96% | SpikeRate=0.069352 | Energy=5.2014 | Eff=0.096050

--- Evaluating T=100 on VAL ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=50.75% | SpikeRate=0.067156 | Energy=6.7156 | Eff=0.075578

--- Evaluating T=100 on TEST ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 20/20 [00:27<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=49.96% | SpikeRate=0.069352 | Energy=6.9352 | Eff=0.072038

===== β = 0.95 =====

--- Evaluating T=10 on VAL ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=51.20% | SpikeRate=0.076037 | Energy=0.7604 | Eff=0.673344

--- Evaluating T=10 on TEST ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.32s/it]
```

```
Skipped 0 problematic batches.
Acc=50.93% | SpikeRate=0.078519 | Energy=0.7852 | Eff=0.648657

--- Evaluating T=25 on VAL ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=51.20% | SpikeRate=0.076037 | Energy=1.9009 | Eff=0.269337

--- Evaluating T=25 on TEST ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.32s/it]
Skipped 0 problematic batches.
Acc=50.93% | SpikeRate=0.078519 | Energy=1.9630 | Eff=0.259463

--- Evaluating T=50 on VAL ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=51.20% | SpikeRate=0.076037 | Energy=3.8018 | Eff=0.134669

--- Evaluating T=50 on TEST ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [01:31<00:00,  4.56s/it]
Skipped 0 problematic batches.
Acc=50.93% | SpikeRate=0.078519 | Energy=3.9260 | Eff=0.129731

--- Evaluating T=75 on VAL ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.37s/it]
Skipped 0 problematic batches.
Acc=51.20% | SpikeRate=0.076037 | Energy=5.7028 | Eff=0.089779

--- Evaluating T=75 on TEST ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=50.93% | SpikeRate=0.078519 | Energy=5.8889 | Eff=0.086488

--- Evaluating T=100 on VAL ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=51.20% | SpikeRate=0.076037 | Energy=7.6037 | Eff=0.067334

--- Evaluating T=100 on TEST ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.32s/it]
```

```
Skipped 0 problematic batches.
Acc=50.93% | SpikeRate=0.078519 | Energy=7.8519 | Eff=0.064866

===== β = 0.97 =====

--- Evaluating T=10 on VAL ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=51.78% | SpikeRate=0.079791 | Energy=0.7979 | Eff=0.648901

--- Evaluating T=10 on TEST ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.32s/it]
Skipped 0 problematic batches.
Acc=51.22% | SpikeRate=0.082343 | Energy=0.8234 | Eff=0.621976

--- Evaluating T=25 on VAL ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=51.78% | SpikeRate=0.079791 | Energy=1.9948 | Eff=0.259561

--- Evaluating T=25 on TEST ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.32s/it]
Skipped 0 problematic batches.
Acc=51.22% | SpikeRate=0.082343 | Energy=2.0586 | Eff=0.248790

--- Evaluating T=50 on VAL ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=51.78% | SpikeRate=0.079791 | Energy=3.9895 | Eff=0.129780

--- Evaluating T=50 on TEST ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [04:57<00:00, 14.86s/it]
Skipped 0 problematic batches.
Acc=51.22% | SpikeRate=0.082343 | Energy=4.1172 | Eff=0.124395

--- Evaluating T=75 on VAL ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:25<00:00,  1.39s/it]
Skipped 0 problematic batches.
Acc=51.78% | SpikeRate=0.079791 | Energy=5.9843 | Eff=0.086520

--- Evaluating T=75 on TEST ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.34s/it]
```

```
Skipped 0 problematic batches.
Acc=51.22% | SpikeRate=0.082343 | Energy=6.1757 | Eff=0.082930

--- Evaluating T=100 on VAL ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=51.78% | SpikeRate=0.079791 | Energy=7.9791 | Eff=0.064890

--- Evaluating T=100 on TEST ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.34s/it]
Skipped 0 problematic batches.
Acc=51.22% | SpikeRate=0.082343 | Energy=8.2343 | Eff=0.062198

===== β = 0.99 =====

--- Evaluating T=10 on VAL ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:25<00:00,  1.43s/it]
Skipped 0 problematic batches.
Acc=52.13% | SpikeRate=0.083659 | Energy=0.8366 | Eff=0.623142

--- Evaluating T=10 on TEST ---
SNN Eval @T=10: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.33s/it]
Skipped 0 problematic batches.
Acc=51.46% | SpikeRate=0.086304 | Energy=0.8630 | Eff=0.596249

--- Evaluating T=25 on VAL ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.37s/it]
Skipped 0 problematic batches.
Acc=52.13% | SpikeRate=0.083659 | Energy=2.0915 | Eff=0.249257

--- Evaluating T=25 on TEST ---
SNN Eval @T=25: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:29<00:00,  1.49s/it]
Skipped 0 problematic batches.
Acc=51.46% | SpikeRate=0.086304 | Energy=2.1576 | Eff=0.238500

--- Evaluating T=50 on VAL ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:26<00:00,  1.47s/it]
Skipped 0 problematic batches.
Acc=52.13% | SpikeRate=0.083659 | Energy=4.1829 | Eff=0.124628

--- Evaluating T=50 on TEST ---
SNN Eval @T=50: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:27<00:00,  1.36s/it]
```

```
Skipped 0 problematic batches.
Acc=51.46% | SpikeRate=0.086304 | Energy=4.3152 | Eff=0.119250

--- Evaluating T=75 on VAL ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.37s/it]
Skipped 0 problematic batches.
Acc=52.13% | SpikeRate=0.083659 | Energy=6.2744 | Eff=0.083086

--- Evaluating T=75 on TEST ---
SNN Eval @T=75: 100%|██████████████████████████████████████████████████
█████████████████| 20/20 [00:26<00:00,  1.35s/it]
Skipped 0 problematic batches.
Acc=51.46% | SpikeRate=0.086304 | Energy=6.4728 | Eff=0.079500

--- Evaluating T=100 on VAL ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 18/18 [00:24<00:00,  1.38s/it]
Skipped 0 problematic batches.
Acc=52.13% | SpikeRate=0.083659 | Energy=8.3659 | Eff=0.062314

--- Evaluating T=100 on TEST ---
SNN Eval @T=100: 100%|█████████████████████████████████████████████████
█████████████████| 20/20 [00:28<00:00,  1.41s/it]
Skipped 0 problematic batches.
Acc=51.46% | SpikeRate=0.086304 | Energy=8.6304 | Eff=0.059625
```

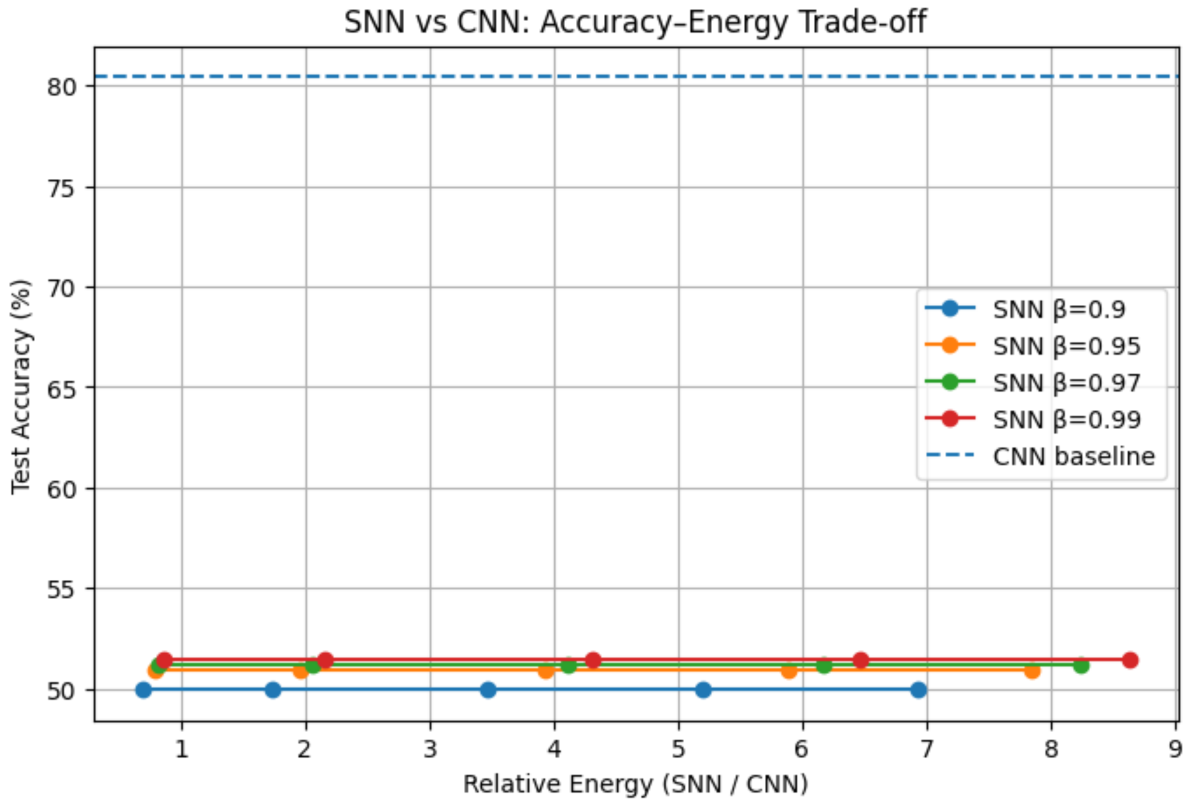
	model	beta	T	val_acc	test_acc	avg_spike_rate	energy_proxy	eff
20	CNN	-	-	81.793961	80.429498	0.000000	1.000000	80.4
0	SNN	0.9	10	50.754885	49.959481	0.069352	0.693517	0.
4	SNN	0.9	100	50.754885	49.959481	0.069352	6.935170	0.0
1	SNN	0.9	25	50.754885	49.959481	0.069352	1.733793	0.
2	SNN	0.9	50	50.754885	49.959481	0.069352	3.467585	0.
3	SNN	0.9	75	50.754885	49.959481	0.069352	5.201378	0.0
5	SNN	0.95	10	51.198934	50.931929	0.078519	0.785190	0.6
9	SNN	0.95	100	51.198934	50.931929	0.078519	7.851904	0.0
6	SNN	0.95	25	51.198934	50.931929	0.078519	1.962976	0.2
7	SNN	0.95	50	51.198934	50.931929	0.078519	3.925952	0
8	SNN	0.95	75	51.198934	50.931929	0.078519	5.888928	0.0
10	SNN	0.97	10	51.776199	51.215559	0.082343	0.823433	0.
14	SNN	0.97	100	51.776199	51.215559	0.082343	8.234333	0.0
11	SNN	0.97	25	51.776199	51.215559	0.082343	2.058583	0.2
12	SNN	0.97	50	51.776199	51.215559	0.082343	4.117166	0.
13	SNN	0.97	75	51.776199	51.215559	0.082343	6.175750	0.0
15	SNN	0.99	10	52.131439	51.458671	0.086304	0.863040	0.5
19	SNN	0.99	100	52.131439	51.458671	0.086304	8.630402	0.0
16	SNN	0.99	25	52.131439	51.458671	0.086304	2.157601	0.2
17	SNN	0.99	50	52.131439	51.458671	0.086304	4.315201	0.
18	SNN	0.99	75	52.131439	51.458671	0.086304	6.472802	0.0

In [18]:

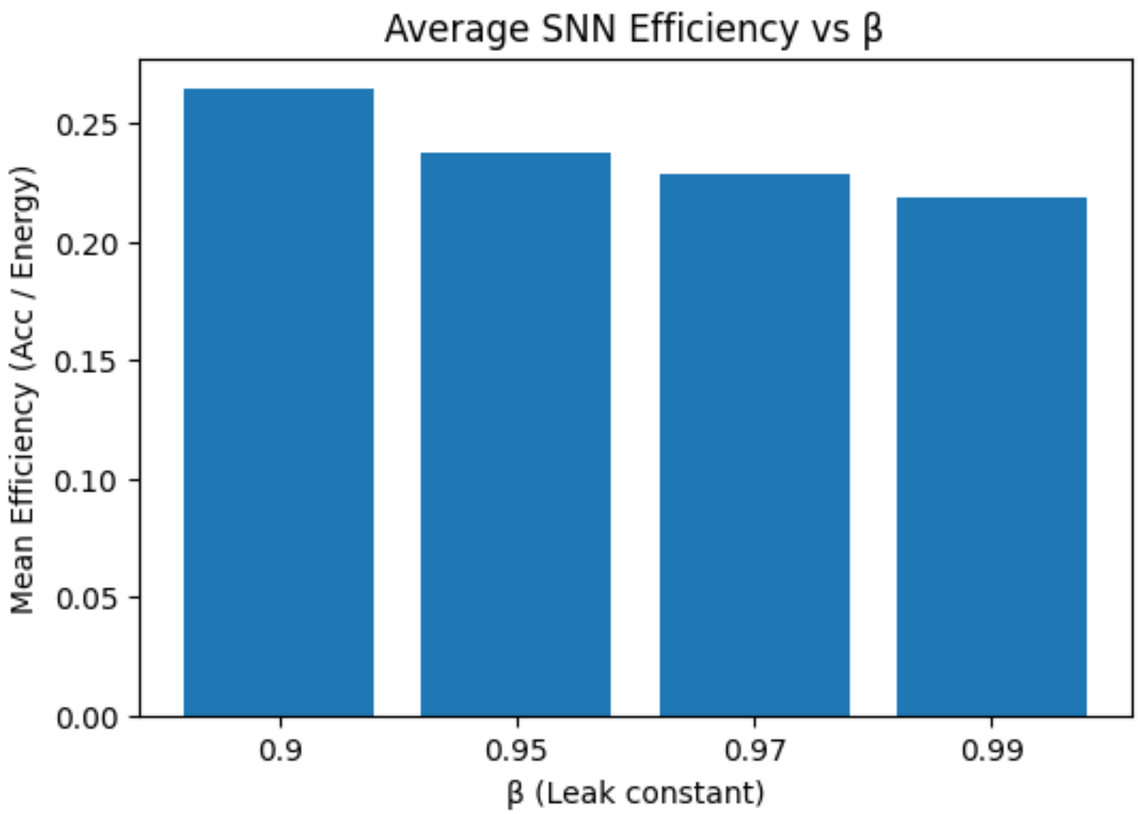
```
# %%
# Ensure numeric consistency
df["beta"] = df["beta"].apply(lambda x: float(x) if isinstance(x, (int
df["T"] = df["T"].apply(lambda x: int(x) if isinstance(x, (int, float)

# Relative energy vs CNN baseline
cnn_energy = df[df["model"] == "CNN"]["energy_proxy"].iloc[0]
df["relative_energy"] = df["energy_proxy"] / cnn_energy

display(df)

# Plot: Test Accuracy vs Relative Energy
plt.figure(figsize=(8, 5))
```

```
for beta in [b for b in df["beta"].unique() if b != "-"]:
    sub = df[(df["model"] == "SNN") & (df["beta"] == beta)]
    plt.plot(sub["relative_energy"], sub["test_acc"], "o-", label=f"SN

plt.axhline(
    y=test_acc_cnn * 100,
    linestyle="--",
    label="CNN baseline"
)

plt.xlabel("Relative Energy (SNN / CNN)")
plt.ylabel("Test Accuracy (%)")
plt.title("SNN vs CNN: Accuracy–Energy Trade-off")
plt.legend()
plt.grid(True)
plt.show()
```

	model	beta	T	val_acc	test_acc	avg_spike_rate	energy_proxy	eff
0	SNN	0.9	10	50.754885	49.959481	0.069352	0.693517	0.
1	SNN	0.9	25	50.754885	49.959481	0.069352	1.733793	0.
2	SNN	0.9	50	50.754885	49.959481	0.069352	3.467585	0.
3	SNN	0.9	75	50.754885	49.959481	0.069352	5.201378	0.0
4	SNN	0.9	100	50.754885	49.959481	0.069352	6.935170	0.0
5	SNN	0.95	10	51.198934	50.931929	0.078519	0.785190	0.6
6	SNN	0.95	25	51.198934	50.931929	0.078519	1.962976	0.2
7	SNN	0.95	50	51.198934	50.931929	0.078519	3.925952	0.
8	SNN	0.95	75	51.198934	50.931929	0.078519	5.888928	0.0
9	SNN	0.95	100	51.198934	50.931929	0.078519	7.851904	0.0
10	SNN	0.97	10	51.776199	51.215559	0.082343	0.823433	0.
11	SNN	0.97	25	51.776199	51.215559	0.082343	2.058583	0.2
12	SNN	0.97	50	51.776199	51.215559	0.082343	4.117166	0.1
13	SNN	0.97	75	51.776199	51.215559	0.082343	6.175750	0.0
14	SNN	0.97	100	51.776199	51.215559	0.082343	8.234333	0.0
15	SNN	0.99	10	52.131439	51.458671	0.086304	0.863040	0.5
16	SNN	0.99	25	52.131439	51.458671	0.086304	2.157601	0.2
17	SNN	0.99	50	52.131439	51.458671	0.086304	4.315201	0.
18	SNN	0.99	75	52.131439	51.458671	0.086304	6.472802	0.0
19	SNN	0.99	100	52.131439	51.458671	0.086304	8.630402	0.0
20	CNN	-	-	81.793961	80.429498	0.000000	1.000000	80.4



In [19]:
```
# %%
snn_rows = df[df["model"] == "SNN"]
eff_by_beta = snn_rows.groupby("beta")["efficiency"].mean().reset_inde

plt.figure(figsize=(6, 4))
plt.bar(eff_by_beta["beta"].astype(str), eff_by_beta["efficiency"])
plt.xlabel("β (Leak constant)")
plt.ylabel("Mean Efficiency (Acc / Energy)")
plt.title("Average SNN Efficiency vs β")
plt.show()

display(eff_by_beta)
```



	beta	efficiency
0	0.90	0.264139
1	0.95	0.237841
2	0.97	0.228058
3	0.99	0.218625

In [20]:
```
# %%
# Example: save the last SNN configuration (e.g., β=0.95, T=50)
beta_best = 0.95
T_best = 50

snn_best = SNN_KWS(cnn_model, num_steps=T_best, beta=beta_best).to(dev
snn_best.eval()

snn_save_path = MODEL_DIR / f"snn_kws_beta{beta_best}_T{T_best}.pt"
torch.save(snn_best.state_dict(), snn_save_path)

print("Saved SNN model to:", snn_save_path)
```

```
Saved SNN model to: /Users/maddy/Desktop/PLEP/Project/CS-576-Final-Proj
ect/saved_models/snn_kws_beta0.95_T50.pt
```

In [ ]:
```
```