

■ Training Code Export (Complete Code - No Truncation)

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■ File: config.py

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=====
1: """
2: Configuration settings for the Neural-Geometric 3D Model Generator
3: Enhanced with dynamic curriculum and adaptive training strategies
4: """
5: from dataclasses import dataclass
6: from typing import Tuple, Dict, Any, Optional, List
7: import torch
8:
9:
10: @dataclass
11: class DataConfig:
12:     """Data-related configuration"""
13:     data_dir: str = "./data/floorplans"
14:     image_size: Tuple[int, int] = (256, 256) # keep full resolution for accuracy
15:     voxel_size: int = 64
16:     batch_size: int = 4 # balance speed & memory
17:     num_workers: int = 8 # faster dataloader (tune per CPU)
18:     augment: bool = True
19:
20:
21: @dataclass
22: class ModelConfig:
23:     """Model architecture configuration optimized for high accuracy"""
24:     input_channels: int = 3
25:     num_classes: int = 5
26:     feature_dim: int = 512 # reduced from 768 ? faster while keeping strong accuracy
27:     num_attributes: int = 6
28:     voxel_size: int = 64
29:     max_polygons: int = 20 # enough for complex layouts
30:     max_points: int = 50 # good detail without huge cost
31:     dropout: float = 0.05
32:     use_attention: bool = True
33:     use_deep_supervision: bool = True
34:
35:     # Auxiliary heads for novel training strategies
36:     use_latent_consistency: bool = True
37:     use_graph_constraints: bool = True
38:     latent_embedding_dim: int = 256
39:
40:
41: @dataclass
42: class CurriculumConfig:
43:     """Dynamic curriculum learning configuration"""
44:     # Adaptive stage transitioning
45:     use_dynamic_curriculum: bool = True
46:     stage_switch_patience: int = 5
47:     min_improvement_threshold: float = 0.001
48:     plateau_detection_window: int = 3
49:
50:     # GradNorm / gradient tracking
51:     gradient_norm_window: int = 100
52:
53:     # Objectives for multi-objective optimization
54:     objectives: Optional[List[str]] = None
55:
56:     # Topology-aware scheduling
57:     topology_schedule: str = "progressive" # "progressive", "linear_ramp", "exponential"
58:     topology_start_weight: float = 0.1
59:     topology_end_weight: float = 1.0
60:     topology_ramp_epochs: int = 20
61:
62:     # config.py (snippet ? add into the existing config class/dict)
63:     # Mixed precision and training conveniences
64:     use_mixed_precision = True # enable AMP
65:     cache_in_memory = False # set True if host RAM can hold dataset
66:     accumulation_steps = 1 # effective batch size multiplier
67:     dvx_step_freq = 1 # run DVX refinement every N steps (1 = every step)
68:     persistent_workers = True # DataLoader persistent workers
69:     prefetch_factor = 4 # DataLoader prefetch
70:     num_workers = 8 # default num workers for DataLoader (tune by CPU)
71:     # Progressive resolution settings (example)
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72:     voxel_size_stage = { "stage1": 32, "stage2": 32, "stage3": 64 } # voxel sizes per stage
73:     image_size_stage = { "stage1": (128,128), "stage2": (192,192), "stage3": (256,256)}
74:
75:
76:     # Loss component scheduling
77:     loss_schedule: Dict[str, str] = None
78:
79:     # Multi-objective optimization (GradNorm)
80:     use_gradnorm: bool = True
81:     gradnorm_alpha: float = 0.12
82:     gradnorm_update_freq: int = 5
83:
84:     # Graph constraint scheduling
85:     graph_weight_schedule: str = "delayed_ramp"
86:     graph_start_epoch: int = 15
87:     graph_end_weight: float = 0.25
88:
89:     def __post_init__(self):
90:         # Provide default loss schedule if not set
91:         if self.loss_schedule is None:
92:             self.loss_schedule = {
93:                 "segmentation": "static",
94:                 "dice": "static",
95:                 "sdf": "early_decay",
96:                 "attributes": "static",
97:                 "polygon": "staged_ramp",
98:                 "voxel": "late_ramp",
99:                 "topology": "progressive",
100:                 "latent_consistency": "mid_ramp",
101:                 "graph": "delayed_ramp",
102:             }
103:
104:         # Default objectives used by GradNorm / trainer monitoring
105:         if self.objectives is None:
106:             self.objectives = [
107:                 "segmentation",
108:                 "dice",
109:                 "sdf",
110:                 "attributes",
111:                 "polygon",
112:                 "voxel",
113:                 "topology",
114:                 "latent_consistency",
115:                 "graph",
116:             ]
117:
118:
119: @dataclass
120: class TrainingConfig:
121:     """Training configuration with adaptive strategies"""
122:     device: str = "cuda" if torch.cuda.is_available() else "cpu"
123:
124:     # Dynamic epoch limits (maxima; curriculum may switch earlier)
125:     max_stage1_epochs: int = 40
126:     max_stage2_epochs: int = 25
127:     max_stage3_epochs: int = 60
128:
129:     # Minimum epochs per stage (avoid switching too early)
130:     min_stage1_epochs: int = 8
131:     min_stage2_epochs: int = 5
132:     min_stage3_epochs: int = 12
133:
134:     # Learning rates (per stage)
135:     stage1_lr: float = 3e-4 # was 3e-4
136:     stage1_weight_decay: float = 1e-5
137:
138:     stage2_lr: float = 1e-4 # was 1e-4
139:     stage2_weight_decay: float = 1e-5
140:
141:     stage3_lr: float = 5e-5 # was 5e-5
142:     stage3_weight_decay: float = 1e-5
143:
144:     # Advanced training techniques

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145:     use_mixed_precision: bool = True
146:     use_cosine_restarts: bool = True
147:     warmup_epochs: int = 5
148:     grad_clip_norm: float = 1.0
149:
150:     # Gradient monitoring for dynamic weighting
151:     track_gradient_norms: bool = True
152:     gradient_norm_window: int = 10 # rolling window for gradient tracking
153:
154:     # Checkpointing
155:     checkpoint_freq: int = 1
156:
157:     # Curriculum configuration
158:     curriculum: CurriculumConfig = None
159:
160:     def __post_init__(self):
161:         if self.curriculum is None:
162:             self.curriculum = CurriculumConfig()
163:
164:
165: @dataclass
166: class LossConfig:
167:     """Loss function weights (will be dynamically adjusted during training)"""
168:     # Base weights (starting values)
169:     seg_weight: float = 1.0
170:     dice_weight: float = 1.0
171:     sdf_weight: float = 0.5
172:     attr_weight: float = 1.0
173:     polygon_weight: float = 1.0
174:     voxel_weight: float = 1.0
175:     topology_weight: float = 0.1 # start low, ramp up
176:
177:     # New loss components
178:     latent_consistency_weight: float = 0.5
179:     graph_constraint_weight: float = 0.3
180:
181:     # Dynamic weighting parameters
182:     enable_dynamic_weighting: bool = True
183:     weight_update_freq: int = 10
184:     weight_momentum: float = 0.9
185:
186:
187: @dataclass
188: class InferenceConfig:
189:     """Inference configuration"""
190:     model_path: str = "final_model.pth"
191:     test_images_dir: str = "./data/test_images"
192:     output_dir: str = "./outputs"
193:     export_intermediate: bool = True
194:     polygon_threshold: float = 0.5
195:
196:
197: # Curriculum stage transition logic
198: class StageTransitionCriteria:
199:     """Defines criteria for automatic stage transitions"""
200:
201:     @staticmethod
202:     def should_transition_from_stage1(train_losses, val_losses, config: CurriculumConfig) -> bool:
203:         """Check if should transition from Stage 1 to Stage 2"""
204:         if len(val_losses) < config.plateau_detection_window:
205:             return False
206:
207:         # Check for plateau in segmentation + dice losses
208:         recent_losses = val_losses[-config.plateau_detection_window:]
209:         if len(recent_losses) < 2:
210:             return False
211:
212:         # Calculate improvement rate
213:         old_avg = sum(recent_losses[:len(recent_losses)//2]) / (len(recent_losses)//2)
214:         new_avg = sum(recent_losses[len(recent_losses)//2:]) / (len(recent_losses) -
+             len(recent_losses)//2)
215:
216:         improvement_rate = (old_avg - new_avg) / (old_avg + 1e-8)

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217:         return improvement_rate < config.min_improvement_threshold
218:
219:     @staticmethod
220:     def should_transition_from_stage2(polygon_losses, config: CurriculumConfig) -> bool:
221:         """Check if should transition from Stage 2 to Stage 3"""
222:         if len(polygon_losses) < config.plateau_detection_window:
223:             return False
224:
225:         # Check polygon loss plateau
226:         recent_losses = polygon_losses[-config.plateau_detection_window:]
227:         if len(recent_losses) < 2:
228:             return False
229:
230:         old_avg = sum(recent_losses[:len(recent_losses)//2]) / (len(recent_losses)//2)
231:         new_avg = sum(recent_losses[len(recent_losses)//2:]) / (len(recent_losses) -
+             len(recent_losses)//2)
232:
233:         improvement_rate = (old_avg - new_avg) / (old_avg + 1e-8)
234:         return improvement_rate < config.min_improvement_threshold
235:
236:
237: # Default configurations (import these in your trainer)
238: DEFAULT_DATA_CONFIG = DataConfig()
239: DEFAULT_MODEL_CONFIG = ModelConfig()
240: DEFAULT_TRAINING_CONFIG = TrainingConfig()
241: DEFAULT_LOSS_CONFIG = LossConfig()
242: DEFAULT_INFERENCE_CONFIG = InferenceConfig()

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■ File: dataset.py

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=====
1: """
2: Dataset classes for the Neural-Geometric 3D Model Generator
3: Enhanced with in-memory caching for faster training
4: """
5:
6: import cv2
7: import json
8: import numpy as np
9: import torch
10: from torch.utils.data import Dataset
11: from pathlib import Path
12: from typing import Dict, List, Tuple, Optional, Union
13: import time
14:
15: from config import DEFAULT_DATA_CONFIG
16:
17:
18: class AdvancedFloorPlanDataset(Dataset):
19:     """
20:     Research-grade dataset with complete ground truth:
21:     - Floorplan image + segmentation mask
22:     - Attribute dictionary (geometric parameters)
23:     - Ground-truth mesh + voxelized occupancy
24:     - Polygon outlines for vectorization supervision
25:
26:     Enhanced with optional in-memory caching for performance
27:     """
28:
29:     def __init__(
30:         self,
31:         data_dir: str = None,
32:         split: str = "train",
33:         image_size: Tuple[int, int] = None,
34:         voxel_size: int = None,
35:         augment: bool = None,
36:         config=None,
37:     ):
38:         # Use config if provided, otherwise defaults from config.py
39:         if config is None:
40:             config = DEFAULT_DATA_CONFIG
41:

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42:         self.data_dir = Path(data_dir or config.data_dir)
43:         self.split = split
44:         self.image_size = image_size or config.image_size
45:         self.voxel_size = voxel_size or config.voxel_size
46:         self.augment = (
47:             augment if augment is not None else config.augment
48:         ) and split == "train"
49:
50:         # Collect all samples that contain every required file
51:         self.samples = self._find_complete_samples()
52:         print(f"Found {len(self.samples)} complete samples for {split}")
53:
54:         # NEW: In-memory caching for performance
55:         self.cache_in_memory = getattr(config, "cache_in_memory", False)
56:         self._cache = None
57:
58:         if self.cache_in_memory and len(self.samples) > 0:
59:             print(f"[DATA] Preloading {len(self.samples)} samples into RAM (cache_in_memory=True).")
60:             print("[DATA] This may take significant memory but will speed up training...")
61:
62:             # Estimate memory usage
63:             estimated_mb = self._estimate_memory_usage()
64:             print(f"[DATA] Estimated memory usage: {estimated_mb:.1f} MB")
65:
66:             start_time = time.time()
67:             self._preload_cache()
68:             load_time = time.time() - start_time
69:             print(f"[DATA] Cache preloading completed in {load_time:.2f}s")
70:
71:     def _estimate_memory_usage(self):
72:         """Estimate memory usage for caching"""
73:         if not self.samples:
74:             return 0.0
75:
76:         H, W = self.image_size
77:         n_samples = len(self.samples)
78:
79:         # Rough estimates in bytes
80:         image_bytes = H * W * 3 # RGB uint8
81:         mask_bytes = H * W # grayscale uint8
82:         voxel_bytes = self.voxel_size ** 3 * 4 # float32
83:         json_bytes = 1024 # rough estimate for params + polygons
84:
85:         if self.voxel_size >= 128:
86:             voxel_gb = (voxel_bytes * n_samples) / (1024**3)
87:             print(f"[WARNING] Large voxel grid ({self.voxel_size}^3) may lead to high memory usage:
+             {voxel_gb:.2f} GB just for voxels")
88:             print("[Warning] Consider reducing voxel_size or disabling cache_in_memory.")
89:
90:         total_per_sample = image_bytes + mask_bytes + voxel_bytes + json_bytes
91:         total_mb = (total_per_sample * n_samples) / (1024 * 1024)
92:
93:         return total_mb
94:
95:     def _preload_cache(self):
96:         """Preload all samples into memory"""
97:         self._cache = []
98:
99:         for i, sample in enumerate(self.samples):
100:             if i % 100 == 0:
101:                 print(f"[DATA] Loading sample {i+1}/{len(self.samples)}")
102:
103:                 try:
104:                     # Load image
105:                     img = cv2.imread(str(sample["image"]))
106:                     if img is None:
107:                         print(f"Warning: Could not load image {sample['image']}")
108:                         continue
109:                     img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
110:                     img = cv2.resize(img, self.image_size) # (W, H) format for cv2.resize
111:
112:                     # Load mask
113:                     mask = cv2.imread(str(sample["mask"]), cv2.IMREAD_GRAYSCALE)

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114:         if mask is None:
115:             print(f"Warning: Could not load mask {sample['mask']}")
116:             continue
117:         mask = cv2.resize(mask, self.image_size, interpolation=cv2.INTER_NEAREST)
118:
119:         # Load voxel data
120:         try:
121:             voxel_data = np.load(sample["voxel"])
122:             vox = voxel_data["voxels"] # Keep as numpy array
123:         except Exception as e:
124:             print(f"Warning: Could not load voxel data {sample['voxel']}: {e}")
125:             # Create dummy voxel data
126:             vox = np.zeros((self.voxel_size, self.voxel_size, self.voxel_size),
+                 dtype=np.float32)
127:
128:         # Load parameters
129:         try:
130:             with open(sample["params"], "r") as f:
131:                 params = json.load(f)
132:         except Exception as e:
133:             print(f"Warning: Could not load params {sample['params']}: {e}")
134:             params = self._get_default_attributes()
135:
136:         # Load polygons
137:         try:
138:             with open(sample["polygon"], "r") as f:
139:                 polygons = json.load(f)
140:         except Exception as e:
141:             print(f"Warning: Could not load polygons {sample['polygon']}: {e}")
142:             polygons = {"walls": []}
143:
144:         self._cache.append({
145:             "image": img,
146:             "mask": mask,
147:             "vox": vox,
148:             "params": params,
149:             "polygons": polygons,
150:             "sample_id": sample["image"].parent.name,
151:         })
152:
153:     except Exception as e:
154:         print(f"Error loading sample {i}: {e}")
155:         continue
156:
157:     def _get_default_attributes(self):
158:         """Return default attributes for missing param files"""
159:         return {
160:             "wall_height": 2.6,
161:             "wall_thickness": 0.15,
162:             "window_base_height": 0.7,
163:             "window_height": 0.95,
164:             "door_height": 2.6,
165:             "pixel_scale": 0.02,
166:         }
167:
168:     # -----
169:     def _find_complete_samples(self):
170:         """Locate samples that contain all the expected files."""
171:         samples = []
172:         split_dir = self.data_dir / self.split
173:
174:         if not split_dir.exists():
175:             print(f"Warning: Split directory {split_dir} does not exist")
176:             return samples
177:
178:         for sample_dir in split_dir.iterdir():
179:             if not sample_dir.is_dir():
180:                 continue
181:
182:             required_files = {
183:                 "image": sample_dir / "image.png",
184:                 "mask": sample_dir / "mask.png",
185:                 "params": sample_dir / "params.json",

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186:         "mesh": sample_dir / "model.obj",
187:         "voxel": sample_dir / "voxel_GT.npz",
188:         "polygon": sample_dir / "polygon.json",
189:     }
190:
191:     if all(f.exists() for f in required_files.values()):
192:         samples.append(required_files)
193:
194:     return samples
195:
196: # -----
197: def __len__(self):
198:     return len(self._cache) if self._cache is not None else len(self.samples)
199:
200: # -----
201: def __getitem__(self, idx):
202:     # Use cached data if available
203:     if self._cache is not None:
204:         cached_sample = self._cache[idx]
205:         image = cached_sample['image']
206:         mask = cached_sample['mask']
207:         vox = cached_sample['vox']
208:         attributes = cached_sample['params']
209:         polygons_gt = cached_sample['polygons']
210:         sample_id = cached_sample['sample_id']
211:     else:
212:         # Fallback: load from disk on-the-fly
213:         sample = self.samples[idx]
214:
215:         # Load image and mask
216:         image = cv2.imread(str(sample["image"]))
217:         image = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)
218:         image = cv2.resize(image, self.image_size)
219:
220:         mask = cv2.imread(str(sample["mask"]), cv2.IMREAD_GRAYSCALE)
221:         mask = cv2.resize(mask, self.image_size, interpolation=cv2.INTER_NEAREST)
222:
223:         # Load attributes
224:         with open(sample["params"], "r") as f:
225:             attributes = json.load(f)
226:
227:         # Load voxel ground truth
228:         voxel_data = np.load(sample["voxel"])
229:         vox = voxel_data["voxels"]
230:
231:         # Load polygon ground truth
232:         with open(sample["polygon"], "r") as f:
233:             polygons_gt = json.load(f)
234:
235:         sample_id = sample["image"].parent.name
236:
237:     # Normalize image to [0,1]
238:     image = image.astype(np.float32) / 255.0
239:
240:     # Clean mask (remove class 5 if present)
241:     if np.any(mask == 5):
242:         print(f"WARNING: Found class 5 in sample {idx}. Verify this class should be removed!")
243:     mask[mask == 5] = 0
244:
245:     # Convert to tensors
246:     image_tensor = torch.from_numpy(image).float().permute(2, 0, 1)
247:     mask_tensor = torch.from_numpy(mask).long()
248:     voxels_tensor = torch.from_numpy(vox.astype(np.float32))
249:
250:     attr_tensor = self._process_attributes(attributes)
251:     polygon_tensor = self._process_polygons(polygons_gt)
252:
253:     # Apply augmentation if enabled
254:     if self.augment:
255:         image_tensor, mask_tensor = self._augment(image_tensor, mask_tensor)
256:
257:     # Add validation before returning
258:     self._validate_sample_data(idx, image_tensor, mask_tensor, attr_tensor, voxels_tensor,

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+         polygon_tensor)
259:
260:     return {
261:         "image": image_tensor,
262:         "mask": mask_tensor,
263:         "attributes": attr_tensor,
264:         "voxels_gt": voxels_tensor,
265:         "polygons_gt": polygon_tensor,
266:         "sample_id": sample_id,
267:     }
268:
269: # -----
270: def _validate_sample_data(self, idx, image, mask, attributes, voxels, polygons):
271:     """Validate sample data for NaN/Inf values"""
272:     tensors_to_check = [
273:         ("image", image),
274:         ("mask", mask),
275:         ("attributes", attributes),
276:         ("voxels", voxels),
277:         ("polygons", polygons["polygons"])
278:     ]
279:
280:     corrupted_data = False
281:
282:     for name, tensor in tensors_to_check:
283:         if torch.isnan(tensor).any():
284:             print(f"ERROR: {name} contains NaN values at sample {idx}")
285:             corrupted_data = True
286:         if torch.isinf(tensor).any():
287:             print(f"ERROR: {name} contains Inf values at sample {idx}")
288:             corrupted_data = True
289:
290:     if corrupted_data:
291:         print(f"WARNING: Corrupted data detected in sample {idx}, replacing with safe fallback
+         values")
292:
293:     # Replace corrupted tensors with safe fallback values
294:     for name, tensor in tensors_to_check:
295:         if torch.isnan(tensor).any() or torch.isinf(tensor).any():
296:             if name == "image":
297:                 # Replace with zeros (black image)
298:                 image.data = torch.zeros_like(image)
299:             elif name == "mask":
300:                 # Replace with zeros (background class)
301:                 mask.data = torch.zeros_like(mask).long()
302:             elif name == "attributes":
303:                 # Replace with reasonable default values (0.5 normalized)
304:                 attributes.data = torch.ones_like(attributes) * 0.5
305:             elif name == "voxels":
306:                 # Replace with empty voxel grid
307:                 voxels.data = torch.zeros_like(voxels)
308:             elif name == "polygons":
309:                 # Replace polygons with zeros
310:                 polygons["polygons"].data = torch.zeros_like(polygons["polygons"])
311:
312: # -----
313: def _process_attributes(self, attributes):
314:     """Convert attribute dictionary to a normalized tensor."""
315:     # Normalize common architectural parameters into [0,1]
316:     attr_list = [
317:         attributes.get("wall_height", 2.6) / 5.0,
318:         attributes.get("wall_thickness", 0.15) / 0.5,
319:         attributes.get("window_base_height", 0.7) / 3.0,
320:         attributes.get("window_height", 0.95) / 2.0,
321:         attributes.get("door_height", 2.6) / 5.0,
322:         attributes.get("pixel_scale", 0.01) / 0.02,
323:     ]
324:
325:     # Ensure no NaN/Inf values in attribute processing
326:     safe_attr_list = []
327:     for val in attr_list:
328:         if np.isnan(val) or np.isinf(val):
329:             safe_attr_list.append(0.5) # Default normalized value

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330:         else:
331:             safe_attr_list.append(max(0.0, min(1.0, val))) # Clamp to [0,1]
332:
333:     return torch.tensor(safe_attr_list, dtype=torch.float32)
334:
335: # -----
336: def _process_polygons(self, polygons_gt):
337:     """Convert polygon ground truth into a fixed tensor representation.
338:     Handles both formats:
339:     1. Nested dict: { "walls": [...], "doors": [...], ... }
340:     2. Flat list: [ {"type": "wall", "points": [...]}, ... ]
341:     """
342:     max_polygons = 30 # number of polygons per sample
343:     max_points = 100 # max points per polygon
344:
345:     processed = torch.zeros(max_polygons, max_points, 2)
346:     valid_mask = torch.zeros(max_polygons, dtype=torch.bool)
347:
348:     poly_idx = 0
349:
350:     try:
351:         # --- Case 1: dict format ---
352:         if isinstance(polygons_gt, dict):
353:             for class_name, polygon_list in polygons_gt.items():
354:                 if not isinstance(polygon_list, list):
355:                     continue
356:                 for polygon in polygon_list:
357:                     if poly_idx >= max_polygons:
358:                         break
359:                     if "points" not in polygon:
360:                         continue
361:
362:                     points = np.array(polygon["points"])
363:                     if len(points) > max_points:
364:                         # Subsample evenly if too many points
365:                         indices = np.linspace(0, len(points) - 1, max_points, dtype=int)
366:                         points = points[indices]
367:
368:                     # Check for NaN/Inf in points
369:                     if np.any(np.isnan(points)) or np.any(np.isinf(points)):
370:                         print(f"Warning: Invalid polygon points detected, skipping polygon")
371:                         continue
372:
373:                     # Normalize to [0,1] relative to image size
374:                     points = points / np.array(self.image_size)
375:                     # Clamp to valid range
376:                     points = np.clip(points, 0.0, 1.0)
377:
378:                     processed[poly_idx, : len(points)] = torch.from_numpy(points).float()
379:                     valid_mask[poly_idx] = True
380:                     poly_idx += 1
381:
382:         # --- Case 2: list format ---
383:         elif isinstance(polygons_gt, list):
384:             for polygon in polygons_gt:
385:                 if poly_idx >= max_polygons:
386:                     break
387:                 if "points" not in polygon:
388:                     continue
389:
390:                 points = np.array(polygon["points"])
391:                 if len(points) > max_points:
392:                     indices = np.linspace(0, len(points) - 1, max_points, dtype=int)
393:                     points = points[indices]
394:
395:                 # Check for NaN/Inf in points
396:                 if np.any(np.isnan(points)) or np.any(np.isinf(points)):
397:                     print(f"Warning: Invalid polygon points detected, skipping polygon")
398:                     continue
399:
400:                 points = points / np.array(self.image_size)
401:                 points = np.clip(points, 0.0, 1.0)
402:

```

```

403:         processed[poly_idx, : len(points)] = torch.from_numpy(points).float()
404:         valid_mask[poly_idx] = True
405:         poly_idx += 1
406:
407:     except Exception as e:
408:         print(f"Warning: Error processing polygons: {e}")
409:         # Return safe empty polygon data
410:         processed = torch.zeros(max_polygons, max_points, 2)
411:         valid_mask = torch.zeros(max_polygons, dtype=torch.bool)
412:
413:     return {"polygons": processed, "valid_mask": valid_mask}
414:
415: # -----
416: def _augment(self, image, mask):
417:     """Enhanced data augmentation with rotations, flips, and intensity changes."""
418:     # Random rotation (multiples of 90° only for architectural data)
419:     if torch.rand(1) < 0.5:
420:         k = torch.randint(1, 4, (1,)).item()
421:         image = torch.rot90(image, k, dims=[1, 2])
422:         mask = torch.rot90(mask, k, dims=[0, 1])
423:
424:     # Random horizontal flip
425:     if torch.rand(1) < 0.5:
426:         image = torch.flip(image, dims=[2])
427:         mask = torch.flip(mask, dims=[1])
428:
429:     # Random vertical flip
430:     if torch.rand(1) < 0.5:
431:         image = torch.flip(image, dims=[1])
432:         mask = torch.flip(mask, dims=[0])
433:
434:     # Slight brightness/contrast adjustment with safety checks
435:     if torch.rand(1) < 0.3:
436:         brightness = torch.rand(1) * 0.2 - 0.1 # ±0.1
437:         contrast = torch.rand(1) * 0.2 + 0.9 # 0.9-1.1
438:         image = torch.clamp(image * contrast + brightness, 0, 1)
439:
440:     # Additional safety check for augmented image
441:     if torch.isnan(image).any() or torch.isinf(image).any():
442:         print("Warning: Augmentation produced invalid values, reverting to original")
443:         # Revert to safe values
444:         image = torch.clamp(image, 0, 1)
445:         image = torch.where(torch.isnan(image) | torch.isinf(image),
446:                             torch.zeros_like(image), image)
447:
448:     return image, mask
449:
450: # -----
451: def get_cache_info(self):
452:     """Return information about caching status"""
453:     return {
454:         "cache_enabled": self.cache_in_memory,
455:         "cache_loaded": self._cache is not None,
456:         "cached_samples": len(self._cache) if self._cache else 0,
457:         "total_samples": len(self.samples),
458:         "estimated_memory_mb": self._estimate_memory_usage() if self.cache_in_memory else 0
459:     }
460:
461: def disable_cache(self):
462:     """Disable caching and free memory"""
463:     if self._cache is not None:
464:         print(f"[DATA] Disabling cache and freeing memory for {len(self._cache)} samples")
465:         self._cache = None
466:         self.cache_in_memory = False
467:
468: def enable_cache(self):
469:     """Enable caching if not already enabled"""
470:     if not self.cache_in_memory and self.samples:
471:         self.cache_in_memory = True
472:         print("[DATA] Enabling cache...")
473:         self._preload_cache()
474:
475:

```

```

476: # =====
477: # Synthetic sample generator for testing without dataset
478: # =====
479: def create_synthetic_data_sample():
480:     """Generate a synthetic floorplan with attributes, voxels, and polygons."""
481:     image = np.ones((256, 256, 3), dtype=np.uint8) * 255
482:     mask = np.zeros((256, 256), dtype=np.uint8)
483:
484:     # Simple square room
485:     room_points = np.array([[50, 50], [200, 50], [200, 200], [50, 200]])
486:     cv2.fillPoly(mask, [room_points], 1) # Room = class 1
487:     cv2.polylines(image, [room_points], True, (0, 0, 0), 3)
488:
489:     # Add door
490:     cv2.rectangle(mask, (90, 50), (110, 70), 2) # Door = class 2
491:     cv2.rectangle(image, (90, 50), (110, 70), (255, 0, 0), -1)
492:
493:     # Attributes
494:     attributes = {
495:         "wall_height": 2.6,
496:         "wall_thickness": 0.15,
497:         "window_base_height": 0.7,
498:         "window_height": 0.95,
499:         "door_height": 2.6,
500:         "pixel_scale": 0.02,
501:     }
502:
503:     # Simple voxel GT
504:     voxels = np.zeros((64, 64, 64), dtype=bool)
505:     voxels[20, 10:50, 10:50] = True
506:
507:     # Polygon GT
508:     polygons = {"walls": [{"points": room_points.tolist()}]}
509:
510:     return image, mask, attributes, voxels, polygons
511:
512:
513: class SyntheticFloorPlanDataset(Dataset):
514:     """
515:     Synthetic dataset for testing and development when real data is not available
516:     """
517:
518:     def __init__(self, num_samples=1000, image_size=(256, 256), voxel_size=64):
519:         self.num_samples = num_samples
520:         self.image_size = image_size
521:         self.voxel_size = voxel_size
522:
523:     def __len__(self):
524:         return self.num_samples
525:
526:     def __getitem__(self, idx):
527:         # Generate deterministic synthetic data based on index
528:         np.random.seed(idx)
529:         torch.manual_seed(idx)
530:
531:         image, mask, attributes, voxels, polygons_gt = create_synthetic_data_sample()
532:
533:         # Convert to tensors
534:         image_tensor = torch.from_numpy(image.astype(np.float32) / 255.0).permute(2, 0, 1)
535:         mask_tensor = torch.from_numpy(mask).long()
536:         voxels_tensor = torch.from_numpy(voxels.astype(np.float32))
537:
538:         # Process attributes and polygons using same methods as main dataset
539:         dataset = AdvancedFloorPlanDataset.__new__(AdvancedFloorPlanDataset)
540:         dataset.image_size = self.image_size
541:
542:         attr_tensor = dataset._process_attributes(attributes)
543:         polygon_tensor = dataset._process_polygons(polygons_gt)
544:
545:         return {
546:             "image": image_tensor,
547:             "mask": mask_tensor,
548:             "attributes": attr_tensor,

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549:         "voxels_gt": voxels_tensor,
550:         "polygons_gt": polygon_tensor,
551:         "sample_id": f"synthetic_{idx:06d}",
552:     }

```

File: evaluation\metrics.py

```

=====
1: """
2: Evaluation metrics and utilities for the Neural-Geometric 3D Model Generator
3: """
4:
5: import torch
6: import numpy as np
7: from torch.utils.data import DataLoader
8:
9: from models.model import NeuralGeometric3DGenerator
10: from dataset import AdvancedFloorPlanDataset
11:
12:
13: def compute_iou(pred, target):
14:     """Compute IoU for segmentation"""
15:     intersection = (pred & target).float().sum()
16:     union = (pred | target).float().sum()
17:     return (intersection / (union + 1e-6)).item()
18:
19:
20: def compute_3d_iou(pred, target):
21:     """Compute 3D IoU for voxel grids"""
22:     pred_bool = pred.bool()
23:     target_bool = target.bool()
24:
25:     intersection = (pred_bool & target_bool).float().sum()
26:     union = (pred_bool | target_bool).float().sum()
27:
28:     return (intersection / (union + 1e-6)).item()
29:
30:
31: def compute_polygon_metrics(pred_polygons, gt_polygons, validity_pred, validity_gt):
32:     """Compute metrics for polygon prediction"""
33:     # Chamfer distance between polygon sets
34:     valid_pred = pred_polygons[validity_pred > 0.5]
35:     valid_gt = gt_polygons[validity_gt]
36:
37:     if len(valid_pred) == 0 or len(valid_gt) == 0:
38:         return {"chamfer_distance": float('inf'), "validity_accuracy": 0.0}
39:
40:     # Simplified chamfer distance computation
41:     chamfer_dist = 0.0
42:     for pred_poly in valid_pred:
43:         min_dist = float('inf')
44:         for gt_poly in valid_gt:
45:             dist = torch.norm(pred_poly - gt_poly, dim=-1).min().item()
46:             min_dist = min(min_dist, dist)
47:         chamfer_dist += min_dist
48:
49:     chamfer_dist /= len(valid_pred)
50:
51:     # Validity accuracy
52:     validity_acc = ((validity_pred > 0.5) == validity_gt).float().mean().item()
53:
54:     return {
55:         "chamfer_distance": chamfer_dist,
56:         "validity_accuracy": validity_acc
57:     }
58:
59:
60: class ModelEvaluator:
61:     """Comprehensive model evaluation"""
62:
63:     def __init__(self, model_path, device="cuda"):
64:         self.device = device

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```

65:         self.model = NeuralGeometric3DGenerator()
66:
67:         # Load model
68:         checkpoint = torch.load(model_path, map_location=device)
69:         self.model.load_state_dict(checkpoint["model_state_dict"])
70:         self.model.to(device)
71:         self.model.eval()
72:
73:         print(f"Loaded model from {model_path}")
74:
75:     def evaluate_dataset(self, test_dataset):
76:         """Comprehensive evaluation on test dataset"""
77:         test_loader = DataLoader(test_dataset, batch_size=1, shuffle=False)
78:
79:         # Metrics storage
80:         metrics = {
81:             "segmentation": {"ious": [], "class_ious": []},
82:             "attributes": {"maes": [], "mses": []},
83:             "voxels": {"ious": [], "dice_scores": []},
84:             "polygons": {"chamfer_distances": [], "validity_accs": []},
85:         }
86:
87:         with torch.no_grad():
88:             for batch_idx, batch in enumerate(test_loader):
89:                 batch = {k: v.to(self.device) if torch.is_tensor(v) else v
90:                          for k, v in batch.items()}
91:
92:                 predictions = self.model(batch["image"])
93:
94:                 # Evaluate segmentation
95:                 seg_metrics = self._evaluate_segmentation(
96:                     predictions["segmentation"], batch["mask"]
97:                 )
98:                 metrics["segmentation"]["ious"].append(seg_metrics["iou"])
99:                 metrics["segmentation"]["class_ious"].append(seg_metrics["class_ious"])
100:
101:                 # Evaluate attributes
102:                 attr_metrics = self._evaluate_attributes(
103:                     predictions["attributes"], batch["attributes"]
104:                 )
105:                 metrics["attributes"]["maes"].append(attr_metrics["mae"])
106:                 metrics["attributes"]["mses"].append(attr_metrics["mse"])
107:
108:                 # Evaluate voxels
109:                 voxel_metrics = self._evaluate_voxels(
110:                     predictions["voxels_pred"], batch["voxels_gt"]
111:                 )
112:                 metrics["voxels"]["ious"].append(voxel_metrics["iou"])
113:                 metrics["voxels"]["dice_scores"].append(voxel_metrics["dice"])
114:
115:                 # Evaluate polygons
116:                 poly_metrics = self._evaluate_polygons(
117:                     predictions["polygons"],
118:                     predictions["polygon_validity"],
119:                     batch["polygons_gt"]
120:                 )
121:                 metrics["polygons"]["chamfer_distances"].append(poly_metrics["chamfer_distance"])
122:                 metrics["polygons"]["validity_accs"].append(poly_metrics["validity_accuracy"])
123:
124:                 if (batch_idx + 1) % 10 == 0:
125:                     print(f"Evaluated {batch_idx + 1}/{len(test_loader)} samples")
126:
127:         return self._compute_summary_metrics(metrics)
128:
129:     def _evaluate_segmentation(self, pred_seg, target_mask):
130:         """Evaluate segmentation performance"""
131:         seg_pred = torch.argmax(pred_seg, dim=1)
132:
133:         # Overall IoU
134:         overall_iou = compute_iou(seg_pred, target_mask)
135:
136:         # Per-class IoU
137:         num_classes = pred_seg.shape[1]

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138:         class_ious = []
139:
140:         for c in range(num_classes):
141:             pred_c = (seg_pred == c)
142:             target_c = (target_mask == c)
143:
144:             if target_c.sum() > 0: # Only compute if class exists in ground truth
145:                 iou_c = compute_iou(pred_c, target_c)
146:                 class_ious.append(iou_c)
147:
148:         return {
149:             "iou": overall_iou,
150:             "class_ious": class_ious
151:         }
152:
153:     def _evaluate_attributes(self, pred_attrs, target_attrs):
154:         """Evaluate attribute prediction"""
155:         mae = torch.mean(torch.abs(pred_attrs - target_attrs)).item()
156:         mse = torch.mean((pred_attrs - target_attrs) ** 2).item()
157:
158:         return {"mae": mae, "mse": mse}
159:
160:     def _evaluate_voxels(self, pred_voxels, target_voxels):
161:         """Evaluate 3D voxel prediction"""
162:         pred_binary = (torch.sigmoid(pred_voxels) > 0.5).float()
163:         target_float = target_voxels.float()
164:
165:         # 3D IoU
166:         iou_3d = compute_3d_iou(pred_binary, target_float)
167:
168:         # 3D Dice score
169:         intersection = (pred_binary * target_float).sum()
170:         dice = (2 * intersection) / (pred_binary.sum() + target_float.sum() + 1e-6)
171:
172:         return {
173:             "iou": iou_3d,
174:             "dice": dice.item()
175:         }
176:
177:     def _evaluate_polygons(self, pred_polygons, pred_validity, gt_polygons):
178:         """Evaluate polygon prediction"""
179:         return compute_polygon_metrics(
180:             pred_polygons[0],
181:             gt_polygons["polygons"][0],
182:             pred_validity[0],
183:             gt_polygons["valid_mask"][0]
184:         )
185:
186:     def _compute_summary_metrics(self, metrics):
187:         """Compute summary statistics"""
188:         summary = {}
189:
190:         # Segmentation
191:         summary["segmentation_mIoU"] = np.mean(metrics["segmentation"]["ious"])
192:         summary["segmentation_std"] = np.std(metrics["segmentation"]["ious"])
193:
194:         # Attributes
195:         summary["attribute_MAE"] = np.mean(metrics["attributes"]["maes"])
196:         summary["attribute_MAE_std"] = np.std(metrics["attributes"]["maes"])
197:
198:         # Voxels
199:         summary["voxel_mIoU"] = np.mean(metrics["voxels"]["ious"])
200:         summary["voxel_mIoU_std"] = np.std(metrics["voxels"]["ious"])
201:         summary["voxel_dice"] = np.mean(metrics["voxels"]["dice_scores"])
202:
203:         # Polygons
204:         valid_chamfer = [d for d in metrics["polygons"]["chamfer_distances"] if d != float('inf')]
205:         if valid_chamfer:
206:             summary["polygon_chamfer"] = np.mean(valid_chamfer)
207:             summary["polygon_chamfer_std"] = np.std(valid_chamfer)
208:         else:
209:             summary["polygon_chamfer"] = float('inf')
210:             summary["polygon_chamfer_std"] = 0.0

```

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211:
212:         summary["polygon_validity_acc"] = np.mean(metrics["polygons"]["validity_accs"])
213:
214:         return summary
215:
216:     def print_evaluation_results(self, summary):
217:         """Print formatted evaluation results"""
218:         print("=" * 60)
219:         print("COMPREHENSIVE EVALUATION RESULTS")
220:         print("=" * 60)
221:
222:         print(f"Segmentation mIoU: {summary['segmentation_mIoU']:.4f} ±
+         {summary['segmentation_std']:.4f}")
223:         print(f"Attribute MAE: {summary['attribute_MAE']:.4f} ± {summary['attribute_MAE_std']:.4f}")
224:         print(f"Voxel 3D mIoU: {summary['voxel_mIoU']:.4f} ± {summary['voxel_mIoU_std']:.4f}")
225:         print(f"Voxel Dice Score: {summary['voxel_dice']:.4f}")
226:
227:         if summary['polygon_chamfer'] != float('inf'):
228:             print(f"Polygon Chamfer Distance: {summary['polygon_chamfer']:.4f} ±
+             {summary['polygon_chamfer_std']:.4f}")
229:         else:
230:             print("Polygon Chamfer Distance: No valid polygons")
231:
232:         print(f"Polygon Validity Accuracy: {summary['polygon_validity_acc']:.4f}")
233:         print("=" * 60)
234:
235:
236:     def evaluate_model(model_path, data_dir="./data/floorplans"):
237:         """Standalone evaluation function"""
238:         # Load test dataset
239:         test_dataset = AdvancedFloorPlanDataset(data_dir, split="test")
240:
241:         if len(test_dataset) == 0:
242:             print("No test samples found!")
243:             return None
244:
245:         # Create evaluator
246:         evaluator = ModelEvaluator(model_path)
247:
248:         # Run evaluation
249:         summary = evaluator.evaluate_dataset(test_dataset)
250:
251:         # Print results
252:         evaluator.print_evaluation_results(summary)
253:
254:         return summary

```

■ File: inference\engine.py

```

=====
1: """
2: Research-grade inference engine for 2D to 3D floorplan generation
3: """
4:
5: import torch
6: import cv2
7: import numpy as np
8: import json
9: import trimesh
10: from pathlib import Path
11:
12: from models.model import NeuralGeometric3DGenerator
13: from config import DEFAULT_INFERENCE_CONFIG
14:
15:
16: class ResearchInferenceEngine:
17:     """
18:     Complete inference system that converts 2D floorplans to 3D models
19:     following the deterministic export pipeline
20:     """
21:
22:     def __init__(self, model_path=None, device="cuda", config=None):

```



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23:         if config is None:
24:             config = DEFAULT_INFERENCE_CONFIG
25:
26:         self.device = device
27:         self.config = config
28:         self.model = NeuralGeometric3DGenerator()
29:
30:         # Load trained model
31:         model_path = model_path or config.model_path
32:         checkpoint = torch.load(model_path, map_location=device)
33:         self.model.load_state_dict(checkpoint["model_state_dict"])
34:         self.model.to(device)
35:         self.model.eval()
36:
37:         print(f"Loaded trained model from {model_path}")
38:
39:     def generate_3d_model(
40:         self,
41:         image_path: str,
42:         output_path: str,
43:         export_intermediate: bool = None
44:     ):
45:         """
46:         Complete pipeline: Image -> Segmentation -> Polygons -> 3D Model
47:         """
48:         export_intermediate = export_intermediate or self.config.export_intermediate
49:
50:         # Load and preprocess image
51:         image = self._load_image(image_path)
52:
53:         with torch.no_grad():
54:             # Neural network inference
55:             predictions = self.model(image)
56:
57:             # Extract predictions
58:             segmentation = predictions["segmentation"]
59:             attributes = predictions["attributes"]
60:             polygons = predictions["polygons"]
61:             validity = predictions["polygon_validity"]
62:
63:             print("Neural network inference complete")
64:
65:             # Convert to deterministic representations
66:             mask_np = self._extract_mask(segmentation)
67:             attributes_dict = self._extract_attributes(attributes)
68:             polygons_list = self._extract_polygons(polygons, validity)
69:
70:             print(f"Extracted: {len(polygons_list)} valid polygons")
71:
72:             # Export intermediate results if requested
73:             if export_intermediate:
74:                 self._export_intermediates(
75:                     mask_np, attributes_dict, polygons_list, Path(output_path).parent
76:                 )
77:
78:             # Generate 3D model using deterministic pipeline
79:             success = self._generate_deterministic_3d(
80:                 mask_np, attributes_dict, polygons_list, output_path
81:             )
82:
83:             return success
84:
85:     def _load_image(self, image_path):
86:         """Load and preprocess input image"""
87:         image = cv2.imread(image_path)
88:         if image is None:
89:             raise ValueError(f"Could not load image from {image_path}")
90:
91:         image = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)
92:         image = cv2.resize(image, (256, 256))
93:         image = torch.from_numpy(image / 255.0).float()
94:         image = image.permute(2, 0, 1).unsqueeze(0)
95:         return image.to(self.device)

```

```

96:
97: def _extract_mask(self, segmentation):
98:     """Convert soft segmentation to hard mask"""
99:     seg_pred = torch.argmax(segmentation, dim=1)
100:     mask_np = seg_pred.squeeze().cpu().numpy().astype(np.uint8)
101:     return mask_np
102:
103: def _extract_attributes(self, attributes):
104:     """Convert normalized attributes back to physical values"""
105:     attr_np = attributes.squeeze().cpu().numpy()
106:
107:     # Denormalize (reverse of normalization in dataset)
108:     attributes_dict = {
109:         "wall_height": float(attr_np[0] * 5.0),
110:         "wall_thickness": float(attr_np[1] * 0.5),
111:         "window_base_height": float(attr_np[2] * 3.0),
112:         "window_height": float(attr_np[3] * 2.0),
113:         "door_height": float(attr_np[4] * 5.0),
114:         "pixel_scale": float(attr_np[5] * 0.02),
115:     }
116:
117:     return attributes_dict
118:
119: def _extract_polygons(self, polygons, validity, threshold=None):
120:     """Extract valid polygons from network predictions"""
121:     threshold = threshold or self.config.polygon_threshold
122:     batch_size, num_polys, num_points, _ = polygons.shape
123:
124:     polygons_list = []
125:
126:     for poly_idx in range(num_polys):
127:         if validity[0, poly_idx] > threshold: # Only valid polygons
128:             poly_points = polygons[0, poly_idx].cpu().numpy()
129:
130:             # Remove zero-padded points
131:             valid_points = poly_points[poly_points.sum(axis=1) > 0]
132:
133:             if len(valid_points) >= 3: # Minimum for a polygon
134:                 # Convert to image coordinates (assuming 256x256 input)
135:                 valid_points = valid_points * 256
136:                 polygons_list.append(
137:                     {
138:                         "points": valid_points.tolist(),
139:                         "class": "wall", # Simplified - in practice classify polygon type
140:                     }
141:                 )
142:
143:     return polygons_list
144:
145: def _export_intermediates(self, mask, attributes, polygons, output_dir):
146:     """Export intermediate results for debugging/analysis"""
147:     output_dir = Path(output_dir)
148:     output_dir.mkdir(exist_ok=True)
149:
150:     # Export mask
151:     cv2.imwrite(str(output_dir / "predicted_mask.png"), mask * 50)
152:
153:     # Export attributes
154:     with open(output_dir / "predicted_attributes.json", "w") as f:
155:         json.dump(attributes, f, indent=2)
156:
157:     # Export polygons
158:     with open(output_dir / "predicted_polygons.json", "w") as f:
159:         json.dump(polygons, f, indent=2)
160:
161:     # Visualize polygons on mask
162:     vis_img = np.zeros((256, 256, 3), dtype=np.uint8)
163:     vis_img[:, :, 0] = mask * 50 # Background
164:
165:     for poly in polygons:
166:         points = np.array(poly["points"], dtype=np.int32)
167:         cv2.polylines(vis_img, [points], True, (0, 255, 0), 2)
168:

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169:         cv2.imwrite(str(output_dir / "polygon_visualization.png"), vis_img)
170:
171:         print(f"Intermediate results exported to {output_dir}")
172:
173:     def _generate_deterministic_3d(self, mask, attributes, polygons, output_path):
174:         """Generate 3D model using deterministic geometric operations"""
175:         try:
176:             # Initialize mesh components
177:             vertices = []
178:             faces = []
179:             vertex_count = 0
180:
181:             # Extract geometric parameters
182:             wall_height = attributes.get("wall_height", 2.6)
183:             wall_thickness = attributes.get("wall_thickness", 0.15)
184:             pixel_scale = attributes.get("pixel_scale", 0.01)
185:
186:             print(
187:                 f"Generating 3D model with wall_height={wall_height:.2f}m,
+                 thickness={wall_thickness:.2f}m"
188:             )
189:
190:             # Process each polygon (walls, rooms, etc.)
191:             for poly_idx, polygon in enumerate(polygons):
192:                 poly_vertices, poly_faces = self._extrude_polygon_3d(
193:                     polygon["points"],
194:                     wall_height,
195:                     wall_thickness,
196:                     pixel_scale,
197:                     vertex_count,
198:                 )
199:
200:                 vertices.extend(poly_vertices)
201:                 faces.extend(poly_faces)
202:                 vertex_count += len(poly_vertices)
203:
204:             # Add floor and ceiling
205:             floor_verts, floor_faces = self._generate_floor_ceiling(
206:                 mask, pixel_scale, wall_height, vertex_count
207:             )
208:             vertices.extend(floor_verts)
209:             faces.extend(floor_faces)
210:
211:             if len(vertices) == 0:
212:                 print("No geometry generated")
213:                 return False
214:
215:             # Create mesh
216:             mesh = trimesh.Trimesh(vertices=np.array(vertices), faces=np.array(faces))
217:
218:             # Clean up mesh
219:             mesh.remove_duplicate_faces()
220:             mesh.remove_unreferenced_vertices()
221:             mesh.fix_normals()
222:
223:             # Export
224:             mesh.export(output_path)
225:             print(f"3D model exported to {output_path}")
226:             print(
227:                 f"Mesh statistics: {len(mesh.vertices)} vertices, {len(mesh.faces)} faces"
228:             )
229:
230:             return True
231:
232:         except Exception as e:
233:             print(f"Error generating 3D model: {str(e)}")
234:             return False
235:
236:     def _extrude_polygon_3d(self, points, height, thickness, scale, vertex_offset):
237:         """Extrude a 2D polygon to create 3D wall geometry"""
238:         vertices = []
239:         faces = []
240:

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241:         # Convert points to 3D coordinates
242:         points_3d = []
243:         for point in points:
244:             x = (point[0] - 128) * scale # Center and scale
245:             z = (128 - point[1]) * scale # Flip Y and scale
246:             points_3d.append([x, 0, z])
247:
248:         # Create bottom vertices (y=0)
249:         bottom_outer = points_3d
250:         bottom_inner = self._inset_polygon(points_3d, thickness)
251:
252:         # Create top vertices (y=height)
253:         top_outer = [[p[0], height, p[2]] for p in bottom_outer]
254:         top_inner = [[p[0], height, p[2]] for p in bottom_inner]
255:
256:         # Combine all vertices
257:         all_vertices = bottom_outer + bottom_inner + top_outer + top_inner
258:         vertices.extend(all_vertices)
259:
260:         n_points = len(points_3d)
261:
262:         # Generate faces for walls
263:         for i in range(n_points):
264:             next_i = (i + 1) % n_points
265:
266:             # Outer wall faces
267:             v1 = vertex_offset + i # bottom outer
268:             v2 = vertex_offset + next_i # bottom outer next
269:             v3 = vertex_offset + 2 * n_points + next_i # top outer next
270:             v4 = vertex_offset + 2 * n_points + i # top outer
271:
272:             faces.extend([[v1, v2, v3], [v1, v3, v4]])
273:
274:             # Inner wall faces (reverse winding)
275:             v1 = vertex_offset + n_points + i # bottom inner
276:             v2 = vertex_offset + n_points + next_i # bottom inner next
277:             v3 = vertex_offset + 3 * n_points + next_i # top inner next
278:             v4 = vertex_offset + 3 * n_points + i # top inner
279:
280:             faces.extend([[v1, v3, v2], [v1, v4, v3]])
281:
282:         # Top cap (between outer and inner)
283:         for i in range(n_points):
284:             next_i = (i + 1) % n_points
285:
286:             v1 = vertex_offset + 2 * n_points + i # top outer
287:             v2 = vertex_offset + 2 * n_points + next_i # top outer next
288:             v3 = vertex_offset + 3 * n_points + next_i # top inner next
289:             v4 = vertex_offset + 3 * n_points + i # top inner
290:
291:             faces.extend([[v1, v2, v3], [v1, v3, v4]])
292:
293:         # Bottom cap (between outer and inner)
294:         for i in range(n_points):
295:             next_i = (i + 1) % n_points
296:
297:             v1 = vertex_offset + i # bottom outer
298:             v2 = vertex_offset + next_i # bottom outer next
299:             v3 = vertex_offset + n_points + next_i # bottom inner next
300:             v4 = vertex_offset + n_points + i # bottom inner
301:
302:             faces.extend([[v1, v3, v2], [v1, v4, v3]])
303:
304:         return vertices, faces
305:
306:     def _inset_polygon(self, points, inset_distance):
307:         """Create inset polygon for wall thickness"""
308:         if len(points) < 3:
309:             return points
310:
311:         # Simple inset by moving each point inward along angle bisector
312:         inset_points = []
313:         n = len(points)

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314:
315:     for i in range(n):
316:         prev_i = (i - 1) % n
317:         next_i = (i + 1) % n
318:
319:         p_prev = np.array(points[prev_i])
320:         p_curr = np.array(points[i])
321:         p_next = np.array(points[next_i])
322:
323:         # Vectors to adjacent points
324:         v1 = p_curr - p_prev
325:         v2 = p_next - p_curr
326:
327:         # Normalize vectors (in XZ plane, ignore Y)
328:         v1_norm = np.array([v1[0], 0, v1[2]])
329:         v2_norm = np.array([v2[0], 0, v2[2]])
330:
331:         v1_len = np.linalg.norm(v1_norm)
332:         v2_len = np.linalg.norm(v2_norm)
333:
334:         if v1_len > 1e-6:
335:             v1_norm /= v1_len
336:         if v2_len > 1e-6:
337:             v2_norm /= v2_len
338:
339:         # Angle bisector
340:         bisector = v1_norm + v2_norm
341:         bisector_len = np.linalg.norm(bisector)
342:
343:         if bisector_len > 1e-6:
344:             bisector /= bisector_len
345:
346:         # Move point inward
347:         inset_point = p_curr - bisector * inset_distance
348:         inset_points.append([inset_point[0], inset_point[1], inset_point[2]])
349:     else:
350:         inset_points.append(points[i])
351:
352: return inset_points
353:
354: def _generate_floor_ceiling(self, mask, scale, wall_height, vertex_offset):
355:     """Generate floor and ceiling geometry from segmentation mask"""
356:     vertices = []
357:     faces = []
358:
359:     # Find floor regions (assuming class 0 = floor/room)
360:     floor_mask = (mask == 0).astype(np.uint8)
361:
362:     # Find contours
363:     contours, _ = cv2.findContours(
364:         floor_mask, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE
365:     )
366:
367:     for contour in contours:
368:         if cv2.contourArea(contour) < 100: # Skip small regions
369:             continue
370:
371:         # Simplify contour
372:         epsilon = 0.02 * cv2.arcLength(contour, True)
373:         approx = cv2.approxPolyDP(contour, epsilon, True)
374:
375:         if len(approx) < 3:
376:             continue
377:
378:         # Convert to 3D coordinates
379:         floor_points = []
380:         for point in approx.reshape(-1, 2):
381:             x = (point[0] - 128) * scale
382:             z = (128 - point[1]) * scale
383:             floor_points.append([x, 0, z]) # Floor at y=0
384:
385:         ceiling_points = []
386:         for point in approx.reshape(-1, 2):

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387:         x = (point[0] - 128) * scale
388:         z = (128 - point[1]) * scale
389:         ceiling_points.append([x, wall_height, z]) # Ceiling at y=wall_height
390:
391:     # Add vertices
392:     n_points = len(floor_points)
393:     vertices.extend(floor_points)
394:     vertices.extend(ceiling_points)
395:
396:     # Triangulate floor
397:     if n_points >= 3:
398:         for i in range(1, n_points - 1):
399:             faces.append(
400:                 [vertex_offset, vertex_offset + i + 1, vertex_offset + i]
401:             )
402:
403:     # Triangulate ceiling (reverse winding)
404:     for i in range(1, n_points - 1):
405:         faces.append(
406:             [
407:                 vertex_offset + n_points,
408:                 vertex_offset + n_points + i,
409:                 vertex_offset + n_points + i + 1,
410:             ]
411:         )
412:
413:     vertex_offset += 2 * n_points
414:
415:     return vertices, faces
416:
417: def process_batch(self, image_paths, output_dir):
418:     """Process multiple images in batch"""
419:     output_dir = Path(output_dir)
420:     output_dir.mkdir(exist_ok=True)
421:
422:     results = []
423:
424:     for img_path in image_paths:
425:         img_path = Path(img_path)
426:         print(f"Processing: {img_path.name}")
427:
428:         output_path = output_dir / f"{img_path.stem}_model.obj"
429:
430:         try:
431:             success = self.generate_3d_model(
432:                 str(img_path), str(output_path), export_intermediate=True
433:             )
434:
435:             results.append({
436:                 "input": str(img_path),
437:                 "output": str(output_path),
438:                 "success": success
439:             })
440:
441:             if success:
442:                 print(f"? Generated: {output_path}")
443:             else:
444:                 print(f"? Failed: {img_path.name}")
445:
446:         except Exception as e:
447:             print(f"? Error processing {img_path.name}: {str(e)}")
448:             results.append({
449:                 "input": str(img_path),
450:                 "output": str(output_path),
451:                 "success": False,
452:                 "error": str(e)
453:             })
454:
455:     return results

```

■ File: models\dvx.py

```
=====
1: """
2: Robust Differentiable Vectorization (DVX) module.
3:
4: Improvements vs naive DVX:
5: - Projects backbone feature maps to `feature_dim` if channels don't match via 1x1 conv.
6: - Multi-step iterative refinement (improves final polygon accuracy).
7: - Safe guards for shapes, device handling, and grid-sampling.
8: - Returns init_polygons, final polygons, per-step displacements, and validity scores.
9:
10: Usage:
11: - features: dict of feature maps (e.g. "p2", "p4"), each tensor (B, C, H, W).
12: - segmentation: (B, 1, H_img, W_img) or similar ? only used for optional initialization logic.
13: """
14:
15: from typing import Dict, Any, Optional, Tuple
16: import torch
17: import torch.nn as nn
18: import torch.nn.functional as F
19:
20:
21: class DifferentiableVectorization(nn.Module):
22:     def __init__(
23:         self,
24:         max_polygons: int = 20,
25:         max_points: int = 50,
26:         feature_dim: int = 256,
27:         displacement_scale: float = 0.12,
28:         num_refinement_steps: int = 3,
29:         align_corners: bool = False,
30:         padding_mode: str = "border", # options for grid_sample
31:         use_proj_conv: bool = True,
32:     ):
33:         """
34:         Args:
35:             max_polygons: maximum polygons to predict per image
36:             max_points: number of control points per polygon
37:             feature_dim: number of channels the DVX expects (will project backbone features to this)
38:             displacement_scale: multiplier for predicted displacement (tanh output)
39:             num_refinement_steps: how many iterative refinement steps to apply (>=1)
40:             align_corners: align_corners for F.grid_sample
41:             padding_mode: padding_mode for F.grid_sample
42:             use_proj_conv: whether to use 1x1 conv to project backbone features to feature_dim
43:         +
44:         """
45:         super().__init__()
46:         assert max_points > 2, "max_points must be > 2"
47:         assert num_refinement_steps >= 1
48:
49:         self.max_polygons = int(max_polygons)
50:         self.max_points = int(max_points)
51:         self.feature_dim = int(feature_dim)
52:         self.displacement_scale = float(displacement_scale)
53:         self.num_refinement_steps = int(num_refinement_steps)
54:         self.align_corners = bool(align_corners)
55:         self.padding_mode = padding_mode
56:         self.use_proj_conv = bool(use_proj_conv)
57:
58:         # init_net: from pooled p4 -> flattened -> produce normalized coords in [0,1]
59:         # AdaptiveAvgPool2d(8) -> (B, C, 8, 8) -> flatten -> Linear(C*8*8 -> hidden)
60:         hidden = max(512, feature_dim * 2)
61:         self.init_pool = nn.AdaptiveAvgPool2d(8)
62:
63:         # we'll create a projector conv for p4/p2 channels if necessary at runtime
64:         # but also create an MLP init_net that assumes feature_dim channels after pooling
65:         self.init_mlp = nn.Sequential(
66:             nn.Flatten(),
67:             nn.Linear(self.feature_dim * 8 * 8, hidden),
68:             nn.ReLU(inplace=True),
69:             nn.Linear(hidden, 1024),
70:             nn.ReLU(inplace=True),
71:             nn.Linear(1024, self.max_polygons * self.max_points * 2),

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71:         nn.Sigmoid(),
72:     )
73:
74:     # refinement network: maps (feature_dim + 2) -> displacement in [-1,1]
75:     self.refine_net = nn.Sequential(
76:         nn.Linear(self.feature_dim + 2, 256),
77:         nn.ReLU(inplace=True),
78:         nn.Linear(256, 128),
79:         nn.ReLU(inplace=True),
80:         nn.Linear(128, 2),
81:         nn.Tanh(),
82:     )
83:
84:     # validity net (reads flattened coords only)
85:     self.validity_net = nn.Sequential(
86:         nn.Linear(self.max_points * 2, 128),
87:         nn.ReLU(inplace=True),
88:         nn.Linear(128, 1),
89:         nn.Sigmoid(),
90:     )
91:
92:     # projector convs (create lazily when first seen a feature channel mismatch)
93:     # stored per-key: e.g., self._proj_convs['p2'] = nn.Conv2d(in_ch, feature_dim, 1)
94:     self._proj_convs = nn.ModuleDict()
95:     self._proj_created = set()
96:
97:     def _ensure_projector(self, key: str, in_channels: int):
98:         """
99:         Ensure a 1x1 conv exists that projects `in_channels` -> self.feature_dim for feature map
100:         +         `key`.
101:         """
102:         if not self.use_proj_conv:
103:             return None
104:         if key in self._proj_created:
105:             return self._proj_convs[key]
106:
107:         if in_channels != self.feature_dim:
108:             conv = nn.Conv2d(in_channels, self.feature_dim, kernel_size=1, stride=1, padding=0)
109:             # initialize conv: kaiming
110:             nn.init.kaiming_normal_(conv.weight, a=0.2)
111:             if conv.bias is not None:
112:                 nn.init.zeros_(conv.bias)
113:             self._proj_convs[key] = conv
114:         else:
115:             # identity mapping using 1x1 conv with weights = identity-like is tricky
116:             # Instead simply keep no conv; we'll pass feature as-is
117:             self._proj_convs[key] = nn.Identity()
118:             self._proj_created.add(key)
119:             return self._proj_convs[key]
120:
121:     def _project_feature(self, key: str, feat: torch.Tensor) -> torch.Tensor:
122:         """
123:         Project or verify feature map to have self.feature_dim channels.
124:         If projector conv wasn't present and channels == feature_dim, returns feat unchanged.
125:         """
126:         in_ch = feat.shape[1]
127:         proj = self._ensure_projector(key, in_ch)
128:         if proj is None:
129:             # projection not desired; assert channels match
130:             if in_ch != self.feature_dim:
131:                 raise RuntimeError(
132:                     f"Feature '{key}' channels ({in_ch}) != feature_dim ({self.feature_dim}) "
133:                     "and projection disabled."
134:                 )
135:             return feat
136:         # if proj is Identity, apply it still (fast path)
137:         return proj(feat)
138:
139:     def forward(
140:         self,
141:         features: Dict[str, torch.Tensor],
142:         segmentation: Optional[torch.Tensor] = None,
143:         return_all_steps: bool = False,

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143:     ) -> Dict[str, Any]:
144:         """
145:         features: dict with keys like "p2", "p4" containing tensors (B, C, H, W)
146:         segmentation: optional (B, 1, H_img, W_img) or similar (not strictly required)
147:         return_all_steps: if True returns per-step intermediate polygons & displacements
148:         """
149:         # pick features for init and refinement
150:         p4 = features.get("p4", None)
151:         p2 = features.get("p2", None)
152:
153:         if p4 is None and p2 is None:
154:             raise ValueError("At least one of 'p4' or 'p2' must be present in features.")
155:
156:         # prefer p4 for init; fallback to p2 if not present
157:         init_feat = p4 if p4 is not None else p2
158:         refine_feat = p2 if p2 is not None else p4
159:
160:         B = init_feat.shape[0]
161:
162:         # Project features to feature_dim (if needed)
163:         init_feat = self._project_feature("p4_init", init_feat)
164:         refine_feat = self._project_feature("p2_refine", refine_feat)
165:
166:         # -- Initialize polygons --
167:         # Pool then MLP; ensure init_mlp expects feature_dim channels
168:         pooled = self.init_pool(init_feat) # [B, C', 8, 8]
169:         if pooled.shape[1] != self.feature_dim:
170:             # If the projector returned Identity but pooled channels mismatch, try to apply a
+             runtime projector
171:             pooled = self._project_feature("p4_init_postpool", pooled)
172:
173:         init_logits = self.init_mlp(pooled) # [B, max_polygons * max_points * 2]
174:         init_polygons = init_logits.view(B, self.max_polygons, self.max_points, 2) # normalized
+         [0,1]
175:
176:         # Iterative refinement
177:         polygons = init_polygons.clone()
178:         per_step_displacements = []
179:         for step in range(self.num_refinement_steps):
180:             # sample features at the polygon control-point locations
181:             displ = self._single_refine_step(polygons, refine_feat)
182:             per_step_displacements.append(displ)
183:             polygons = torch.clamp(polygons + displ, 0.0, 1.0)
184:
185:         # final validity
186:         validity = self._predict_validity(polygons)
187:
188:         out: Dict[str, Any] = {
189:             "polygons": polygons, # [B, P, N, 2]
190:             "validity": validity, # [B, P]
191:             "init_polygons": init_polygons,
192:             "refinement_displacements": per_step_displacements, # list of [B, P, N, 2]
193:         }
194:
195:         if return_all_steps:
196:             out["all_step_polygons"] = [
197:                 torch.clamp(init_polygons + sum(per_step_displacements[:i + 1]), 0.0, 1.0)
198:                 for i in range(len(per_step_displacements))
199:             ]
200:
201:         return out
202:
203:     def _single_refine_step(self, polygons: torch.Tensor, feature_map: torch.Tensor) ->
+         torch.Tensor:
204:         """
205:         One refinement step: sample features at polygon points, predict displacement (scaled),
+         return displacement.
206:         polygons: [B, P, N, 2] in [0,1]
207:         feature_map: [B, C, H, W] with C == feature_dim (or projected)
208:         returns displacement: [B, P, N, 2] in [-displacement_scale, displacement_scale]
209:         """
210:         B, P, N, _ = polygons.shape
211:         # flatten pts to sample

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212:         coords = polygons.view(B, -1, 2) # [B, P*N, 2], coords in [0,1]
213:         grid = coords * 2.0 - 1.0 # to [-1,1]
214:         # grid_sample expects (B, H_out, W_out, 2); use W_out=1
215:         grid_sample = grid.view(B, -1, 1, 2)
216:         sampled = F.grid_sample(
217:             feature_map,
218:             grid_sample,
219:             mode="bilinear",
220:             padding_mode=self.padding_mode,
221:             align_corners=self.align_corners,
222:         ) # [B, C, P*N, 1]
223:         sampled = sampled.squeeze(-1).permute(0, 2, 1).contiguous() # [B, P*N, C]
224:
225:         # combine sampled features and coords (coords in [0,1])
226:         input_feats = torch.cat([sampled, coords], dim=-1) # [B, P*N, C+2]
227:         # predict displacements in [-1,1] via tanh on last layer
228:         disp = self.refine_net(input_feats) # [B, P*N, 2], values ~[-1,1]
229:         disp = disp.view(B, P, N, 2)
230:         disp = disp * self.displacement_scale # scale
231:         return disp
232:
233:     def _predict_validity(self, polygons: torch.Tensor) -> torch.Tensor:
234:         B, P, N, _ = polygons.shape
235:         if N != self.max_points:
236:             # If someone truncated or padded points, adapt: flatten to last dim whatever it is
237:             poly_flat = polygons.view(B * P, -1)
238:         else:
239:             poly_flat = polygons.view(B * P, -1)
240:         validity = self.validity_net(poly_flat) # [B*P, 1]
241:         validity = validity.view(B, P)
242:         return validity
243:
244:
245: # ----- quick unit test / smoke test -----
246: def _smoke_test():
247:     torch.manual_seed(0)
248:     B = 2
249:     C1 = 384 # different from feature_dim to test projector conv
250:     C2 = 128
251:     H2, W2 = 64, 64
252:     H4, W4 = 16, 16
253:
254:     # create dummy backbone features with different channels
255:     p2 = torch.randn(B, C1, H2, W2)
256:     p4 = torch.randn(B, C2, H4, W4)
257:     seg = torch.rand(B, 1, H2 * 4, W2 * 4) # just a placeholder
258:
259:     dvx = DifferentiableVectorization(
260:         max_polygons=4,
261:         max_points=16,
262:         feature_dim=256,
263:         displacement_scale=0.08,
264:         num_refinement_steps=3,
265:         align_corners=False,
266:         padding_mode="border",
267:         use_proj_conv=True,
268:     )
269:
270:     # ensure module moves projector convs to device when dvx.to(device) called
271:     dvx = dvx.eval() # inference mode ok
272:     # Forward pass
273:     out = dvx({"p2": p2, "p4": p4}, seg, return_all_steps=True)
274:     print("polygons shape:", out["polygons"].shape) # expected [B, P, N, 2]
275:     print("validity shape:", out["validity"].shape) # expected [B, P]
276:     print("init shape:", out["init_polygons"].shape)
277:     print("refinement steps:", len(out["refinement_displacements"]))
278:     # check ranges
279:     assert out["polygons"].min().item() >= 0.0 - 1e-6
280:     assert out["polygons"].max().item() <= 1.0 + 1e-6
281:     print("smoke test passed")
282:
283:
284: if __name__ == "__main__":

```

```
285:     _smoke_test()
```

■ File: models\encoder.py

```
=====
1: """
2: Encoder architecture for multi-scale feature extraction
3: """
4:
5: import torch
6: import torch.nn as nn
7: import torch.nn.functional as F
8:
9:
10: class ResidualBlock(nn.Module):
11:     """Basic residual block for the encoder"""
12:
13:     def __init__(self, in_channels, out_channels, stride=1):
14:         super().__init__()
15:
16:         self.conv1 = nn.Conv2d(in_channels, out_channels, 3, stride, 1, bias=False)
17:         self.bn1 = nn.BatchNorm2d(out_channels)
18:         self.conv2 = nn.Conv2d(out_channels, out_channels, 3, 1, 1, bias=False)
19:         self.bn2 = nn.BatchNorm2d(out_channels)
20:
21:         self.shortcut = nn.Sequential()
22:         if stride != 1 or in_channels != out_channels:
23:             self.shortcut = nn.Sequential(
24:                 nn.Conv2d(in_channels, out_channels, 1, stride, bias=False),
25:                 nn.BatchNorm2d(out_channels),
26:             )
27:
28:     def forward(self, x):
29:         out = F.relu(self.bn1(self.conv1(x)))
30:         out = self.bn2(self.conv2(out))
31:         out += self.shortcut(x)
32:         return F.relu(out)
33:
34:
35: class MultiScaleEncoder(nn.Module):
36:     """
37:     Advanced encoder with skip connections and multi-scale feature extraction
38:     Based on ResNet architecture with Feature Pyramid Network (FPN)
39:     """
40:
41:     def __init__(self, input_channels=3, feature_dim=512):
42:         super().__init__()
43:
44:         # Stem
45:         self.stem = nn.Sequential(
46:             nn.Conv2d(input_channels, 64, 7, 2, 3, bias=False),
47:             nn.BatchNorm2d(64),
48:             nn.ReLU(inplace=True),
49:             nn.MaxPool2d(3, 2, 1),
50:         )
51:
52:         # ResNet blocks
53:         self.layer1 = self._make_layer(64, 64, 2, stride=1) # 64x64
54:         self.layer2 = self._make_layer(64, 128, 2, stride=2) # 32x32
55:         self.layer3 = self._make_layer(128, 256, 2, stride=2) # 16x16
56:         self.layer4 = self._make_layer(256, 512, 2, stride=2) # 8x8
57:
58:         # FPN lateral connections
59:         self.lateral4 = nn.Conv2d(512, feature_dim, 1)
60:         self.lateral3 = nn.Conv2d(256, feature_dim, 1)
61:         self.lateral2 = nn.Conv2d(128, feature_dim, 1)
62:         self.lateral1 = nn.Conv2d(64, feature_dim, 1)
63:
64:         # FPN output layers
65:         self.smooth4 = nn.Conv2d(feature_dim, feature_dim, 3, 1, 1)
66:         self.smooth3 = nn.Conv2d(feature_dim, feature_dim, 3, 1, 1)
67:         self.smooth2 = nn.Conv2d(feature_dim, feature_dim, 3, 1, 1)
```

```

68:         self.smooth1 = nn.Conv2d(feature_dim, feature_dim, 3, 1, 1)
69:
70:         # Global context
71:         self.global_pool = nn.AdaptiveAvgPool2d(1)
72:         self.global_fc = nn.Sequential(
73:             nn.Linear(512, feature_dim),
74:             nn.ReLU(),
75:             nn.Linear(feature_dim, feature_dim)
76:         )
77:
78:     def _make_layer(self, in_channels, out_channels, blocks, stride=1):
79:         layers = []
80:         layers.append(ResidualBlock(in_channels, out_channels, stride))
81:         for _ in range(1, blocks):
82:             layers.append(ResidualBlock(out_channels, out_channels))
83:         return nn.Sequential(*layers)
84:
85:     def forward(self, x):
86:         # Bottom-up pathway
87:         x = self.stem(x) # 64x64
88:
89:         c1 = self.layer1(x) # 64x64
90:         c2 = self.layer2(c1) # 32x32
91:         c3 = self.layer3(c2) # 16x16
92:         c4 = self.layer4(c3) # 8x8
93:
94:         # Global context
95:         global_feat = self.global_pool(c4).flatten(1)
96:         global_feat = self.global_fc(global_feat)
97:
98:         # Top-down pathway (FPN)
99:         p4 = self.lateral4(c4)
100:        p3 = self.lateral3(c3) + F.interpolate(p4, scale_factor=2)
101:        p2 = self.lateral2(c2) + F.interpolate(p3, scale_factor=2)
102:        p1 = self.lateral1(c1) + F.interpolate(p2, scale_factor=2)
103:
104:        # Smooth
105:        p4 = self.smooth4(p4)
106:        p3 = self.smooth3(p3)
107:        p2 = self.smooth2(p2)
108:        p1 = self.smooth1(p1)
109:
110:        return {
111:            "p1": p1, # 64x64
112:            "p2": p2, # 32x32
113:            "p3": p3, # 16x16
114:            "p4": p4, # 8x8
115:            "global": global_feat,
116:        }

```

File: models\extrusion.py

```

=====
1: """
2: Vectorized Differentiable 3D extrusion module for converting polygons to 3D occupancy
3: Optimized version with GPU-accelerated vectorized operations
4: """
5:
6: import torch
7: import torch.nn as nn
8: import torch.nn.functional as F
9: import math
10: import logging
11:
12:
13: # -----
14: # Logging and sanitization helper
15: # -----
16: logger = logging.getLogger(__name__)
17: if not logger.handlers:
18:     handler = logging.StreamHandler()
19:     handler.setFormatter(logging.Formatter("%(asctime)s | %(levelname)s | %(message)s"))

```

```

20:     logger.addHandler(handler)
21: logger.setLevel(logging.INFO)
22:
23:
24: def _sanitize_normalized_height(value, sample_id=None, default=0.6):
25:     """
26:     Ensure normalized height value is finite and in [0,1].
27:     Returns a float in [0,1].
28:
29:     Args:
30:         value: torch scalar tensor or float
31:         sample_id: optional identifier for logging (string or int)
32:         default: fallback normalized height
33:     """
34:     try:
35:         if isinstance(value, torch.Tensor):
36:             raw = float(value.item())
37:         else:
38:             raw = float(value)
39:     except Exception:
40:         raw = float("nan")
41:
42:     # Build label for logging
43:     sid = f"[sample={sample_id}]" if sample_id is not None else ""
44:
45:     # Check finite
46:     if not math.isfinite(raw):
47:         logger.warning(f"{sid} Invalid wall height value (not finite): {raw}; using default
+         {default}")
48:         raw = default
49:
50:     # Clamp to [0,1]
51:     if raw < 0.0 or raw > 1.0:
52:         logger.warning(f"{sid} Wall height normalized {raw} out of [0,1]; clamping.")
53:         raw = max(0.0, min(1.0, raw))
54:
55:     return raw
56:
57:
58: def _sanitize_tensor(tensor, default_value=0.0, name="tensor"):
59:     """
60:     Sanitize an entire tensor by replacing NaN/Inf values with default.
61:
62:     Args:
63:         tensor: Input tensor
64:         default_value: Value to replace invalid entries with
65:         name: Name for logging
66:
67:     Returns:
68:         Sanitized tensor
69:     """
70:     if tensor.numel() == 0:
71:         return tensor
72:
73:     # Check for any invalid values
74:     invalid_mask = ~torch.isfinite(tensor)
75:     num_invalid = invalid_mask.sum().item()
76:
77:     if num_invalid > 0:
78:         logger.warning(f"Found {num_invalid} invalid values in {name}, replacing with
+         {default_value}")
79:         tensor = tensor.clone()
80:         tensor[invalid_mask] = default_value
81:
82:     return tensor
83:
84:
85: # -----
86: # Main extrusion module
87: # -----
88: class DifferentiableExtrusion(nn.Module):
89:     """
90:     Vectorized Differentiable 3D extrusion module

```

```

91:     Converts polygons + attributes to soft 3D occupancy grids
92:     """
93:
94:     def __init__(self, voxel_size: int = 64):
95:         super().__init__()
96:         self.voxel_size = int(voxel_size)
97:         self.register_buffer("_coords", None)
98:
99:     def _ensure_coords(self, device):
100:         """Initialize or update coordinate grid if needed"""
101:         if (self._coords is None or
102:             self._coords.device != device or
103:             self._coords.shape[0] != (self.voxel_size * self.voxel_size)):
104:
105:             H = W = self.voxel_size
106:             y, x = torch.meshgrid(
107:                 torch.arange(H, device=device),
108:                 torch.arange(W, device=device),
109:                 indexing="ij"
110:             )
111:             coords = torch.stack([x.flatten().float(), y.flatten().float()], dim=1) # [H*W, 2]
112:             coords = coords / float(self.voxel_size - 1)
113:             self.register_buffer("_coords", coords)
114:
115:     def polygon_sdf(self, polygon_xy):
116:         """
117:         Compute signed distance field for a polygon using vectorized operations.
118:         """
119:         device = polygon_xy.device
120:         self._ensure_coords(device)
121:         pts = self._coords # [M, 2]
122:         P = polygon_xy.shape[0]
123:
124:         if P < 2:
125:             return torch.full((pts.shape[0],), 1.0, device=device)
126:
127:         # Sanitize polygon coordinates
128:         polygon_xy = _sanitize_tensor(polygon_xy, default_value=0.0, name="polygon_xy")
129:
130:         v0 = polygon_xy.unsqueeze(1)
131:         v1 = torch.roll(polygon_xy, shifts=-1, dims=0).unsqueeze(1)
132:         pts_exp = pts.unsqueeze(0)
133:
134:         e = v1 - v0
135:         v = pts_exp - v0
136:         e_norm_sq = (e**2).sum(dim=2, keepdim=True) + 1e-8
137:         t = (v * e).sum(dim=2, keepdim=True) / e_norm_sq
138:         t_clamped = t.clamp(0.0, 1.0)
139:
140:         proj = v0 + t_clamped * e
141:         diff = pts_exp - proj
142:         dists = torch.norm(diff, dim=2)
143:
144:         # Sanitize distances before min operation
145:         dists = _sanitize_tensor(dists, default_value=1.0, name="distances")
146:         min_dist_per_point, _ = dists.min(dim=0)
147:
148:         x_pts = pts[:, 0].unsqueeze(0)
149:         y_pts = pts[:, 1].unsqueeze(0)
150:         x0, y0 = v0[:, 0], v0[:, 1]
151:         x1, y1 = v1[:, 0], v1[:, 1]
152:
153:         y_crosses = ((y0 <= y_pts) & (y1 > y_pts)) | ((y1 <= y_pts) & (y0 > y_pts))
154:         inter_x = x0 + (x1 - x0) * ((y_pts - y0) / (y1 - y0 + 1e-8))
155:         crossings = (inter_x > x_pts) & y_crosses
156:         crossing_count = crossings.sum(dim=0)
157:         inside = (crossing_count % 2 == 1)
158:
159:         sdf = min_dist_per_point.clone()
160:         sdf[inside] = -sdf[inside]
161:
162:         # Final sanitization of SDF output
163:         sdf = _sanitize_tensor(sdf, default_value=1.0, name="sdf")

```

```

164:         return sdf
165:
166:     def forward(self, polygons, attributes, validity_scores, sample_ids=None):
167:         """
168:         Convert polygons to 3D voxel occupancy.
169:         sample_ids: optional list/array of identifiers (e.g., filenames or dataset indices)
170:         """
171:         device = polygons.device
172:         B, N, P, _ = polygons.shape
173:         D = H = W = self.voxel_size
174:
175:         # Sanitize input tensors
176:         polygons = _sanitize_tensor(polygons, default_value=0.0, name="input_polygons")
177:         attributes = _sanitize_tensor(attributes, default_value=0.6, name="input_attributes")
178:         validity_scores = _sanitize_tensor(validity_scores, default_value=0.0,
+         name="input_validity_scores")
179:
180:         voxels = torch.zeros((B, D, H, W), device=device)
181:
182:         for b in range(B):
183:             # pick identifier if available
184:             sid = sample_ids[b] if sample_ids is not None else b
185:
186:             # Sanitize height with logging
187:             wall_height_normalized = attributes[b, 0]
188:             sanitized_norm = _sanitize_normalized_height(
189:                 wall_height_normalized, sample_id=sid, default=0.6
190:             )
191:
192:             wall_height_m = sanitized_norm * 5.0
193:             height_frac = wall_height_m / 5.0
194:             height_voxels = int(round(height_frac * D))
195:             height_voxels = max(1, min(D, height_voxels))
196:
197:             # Process each polygon for this batch
198:             validity_mask = validity_scores[b] >= 0.5
199:             if not validity_mask.any():
200:                 continue
201:
202:             combined_mask = torch.zeros((H, W), device=device)
203:             sharpness = 100.0
204:
205:             for n in range(N):
206:                 if not validity_mask[n]:
207:                     continue
208:
209:                 polygon = polygons[b, n] # [P, 2]
210:
211:                 # Filter out zero-padded vertices
212:                 vertex_mask = (polygon.sum(dim=1) != 0.0)
213:                 if vertex_mask.sum().item() < 3:
214:                     continue
215:
216:                 valid_polygon = polygon[vertex_mask]
217:
218:                 # Compute SDF for this polygon
219:                 sdf = self.polygon_sdf(valid_polygon)
220:                 mask = torch.sigmoid(-sdf * sharpness)
221:                 mask_2d = mask.view(H, W)
222:
223:                 # Sanitize mask before combining
224:                 mask_2d = _sanitize_tensor(mask_2d, default_value=0.0, name=f"mask_2d_b{b}_n{n}")
225:                 combined_mask = torch.maximum(combined_mask, mask_2d)
226:
227:                 # Create 3D mask by extruding to the computed height
228:                 mask_3d = combined_mask.unsqueeze(0).expand(height_voxels, -1, -1)
229:
230:                 # Sanitize final mask before assignment
231:                 mask_3d = _sanitize_tensor(mask_3d, default_value=0.0, name=f"final_mask_3d_b{b}")
232:                 voxels[b, :height_voxels] = mask_3d
233:
234:             # Final sanitization of output
235:             voxels = _sanitize_tensor(voxels, default_value=0.0, name="output_voxels")

```

```

236:         return voxels
237:
238:
239: # -----
240: # Fast extrusion module
241: # -----
242: class DifferentiableExtrusionFast(nn.Module):
243:     """
244:     Optimized version that batches polygon processing.
245:     """
246:
247:     def __init__(self, voxel_size: int = 64):
248:         super().__init__()
249:         self.voxel_size = int(voxel_size)
250:         self.register_buffer("_coords", None)
251:
252:     def _ensure_coords(self, device):
253:         if (self._coords is None or
254:             self._coords.device != device or
255:             self._coords.shape[0] != (self.voxel_size * self.voxel_size)):
256:
257:             H = W = self.voxel_size
258:             y, x = torch.meshgrid(
259:                 torch.arange(H, device=device),
260:                 torch.arange(W, device=device),
261:                 indexing="ij"
262:             )
263:             coords = torch.stack([x.flatten().float(), y.flatten().float()], dim=1)
264:             coords = coords / float(self.voxel_size - 1)
265:             self.register_buffer("_coords", coords)
266:
267:     def batch_polygon_sdf(self, polygons_batch, validity_mask):
268:         device = polygons_batch.device
269:         self._ensure_coords(device)
270:
271:         N, P, _ = polygons_batch.shape
272:         M = self._coords.shape[0]
273:         sdfs = torch.full((N, M), 1.0, device=device)
274:
275:         valid_indices = torch.where(validity_mask)[0]
276:         if len(valid_indices) == 0:
277:             return sdfs
278:
279:         valid_polygons = polygons_batch[valid_indices]
280:         for i, poly_idx in enumerate(valid_indices):
281:             poly = valid_polygons[i]
282:             vertex_mask = (poly.sum(dim=1) != 0.0)
283:             if vertex_mask.sum().item() >= 3:
284:                 valid_poly = poly[vertex_mask]
285:                 sdf = self.polygon_sdf(valid_poly)
286:                 sdfs[poly_idx] = sdf
287:
288:         return sdfs
289:
290:     def polygon_sdf(self, polygon_xy):
291:         device = polygon_xy.device
292:         self._ensure_coords(device)
293:         pts = self._coords
294:         P = polygon_xy.shape[0]
295:
296:         if P < 2:
297:             return torch.full((pts.shape[0],), 1.0, device=device)
298:
299:         # Sanitize polygon coordinates
300:         polygon_xy = _sanitize_tensor(polygon_xy, default_value=0.0, name="polygon_xy_fast")
301:
302:         v0 = polygon_xy.unsqueeze(1)
303:         v1 = torch.roll(polygon_xy, shifts=-1, dims=0).unsqueeze(1)
304:         pts_exp = pts.unsqueeze(0)
305:
306:         e = v1 - v0
307:         v = pts_exp - v0
308:         e_norm_sq = (e**2).sum(dim=2, keepdim=True) + 1e-8

```



```

309:         t = (v * e).sum(dim=2, keepdim=True) / e_norm_sq
310:         t_clamped = t.clamp(0.0, 1.0)
311:
312:         proj = v0 + t_clamped * e
313:         diff = pts_exp - proj
314:         dists = torch.norm(diff, dim=2)
315:
316:         # Sanitize distances before min operation
317:         dists = _sanitize_tensor(dists, default_value=1.0, name="distances_fast")
318:         min_dist_per_point, _ = dists.min(dim=0)
319:
320:         x_pts = pts[:, 0].unsqueeze(0)
321:         y_pts = pts[:, 1].unsqueeze(0)
322:         x0, y0 = v0[..., 0], v0[..., 1]
323:         x1, y1 = v1[..., 0], v1[..., 1]
324:
325:         y_crosses = ((y0 <= y_pts) & (y1 > y_pts)) | ((y1 <= y_pts) & (y0 > y_pts))
326:         inter_x = x0 + (x1 - x0) * ((y_pts - y0) / (y1 - y0 + 1e-8))
327:         crossings = (inter_x > x_pts) & y_crosses
328:         crossing_count = crossings.sum(dim=0)
329:         inside = (crossing_count % 2 == 1)
330:
331:         sdf = min_dist_per_point.clone()
332:         sdf[inside] = -sdf[inside]
333:
334:         # Final sanitization of SDF output
335:         sdf = _sanitize_tensor(sdf, default_value=1.0, name="sdf_fast")
336:         return sdf
337:
338:     def forward(self, polygons: torch.Tensor, attributes: torch.Tensor, validity_scores:
+         torch.Tensor) -> torch.Tensor:
339:         device = polygons.device
340:         B, N, P, _ = polygons.shape
341:         D = H = W = self.voxel_size
342:
343:         # Sanitize input tensors
344:         polygons = _sanitize_tensor(polygons, default_value=0.0, name="input_polygons_fast")
345:         attributes = _sanitize_tensor(attributes, default_value=0.6, name="input_attributes_fast")
346:         validity_scores = _sanitize_tensor(validity_scores, default_value=0.0,
+         name="input_validity_scores_fast")
347:
348:         voxels = torch.zeros((B, D, H, W), device=device)
349:
350:         for b in range(B):
351:             validity_mask = validity_scores[b] >= 0.5
352:             if not validity_mask.any():
353:                 continue
354:
355:             sdfs = self.batch_polygon_sdf(polygons[b], validity_mask)
356:
357:             # Sanitize SDFs before sigmoid
358:             sdfs = _sanitize_tensor(sdfs, default_value=1.0, name=f"batch_sdfs_b{b}")
359:
360:             sharpness = 100.0
361:             masks = torch.sigmoid(-sdfs * sharpness)
362:             masks_2d = masks.view(N, H, W)
363:
364:             # Sanitize masks
365:             masks_2d = _sanitize_tensor(masks_2d, default_value=0.0, name=f"masks_2d_b{b}")
366:
367:             # Sanitize height
368:             wall_height_normalized = attributes[b, 0]
369:             sanitized_norm = _sanitize_normalized_height(wall_height_normalized, sample_id=b,
+             default=0.6)
370:             wall_height_m = sanitized_norm * 5.0
371:             height_frac = wall_height_m / 5.0
372:             height_voxels = int(round(height_frac * D))
373:             height_voxels = max(1, min(D, height_voxels))
374:
375:             combined_mask = torch.zeros((H, W), device=device)
376:             for n in range(N):
377:                 if validity_mask[n]:
378:                     combined_mask = torch.maximum(combined_mask, masks_2d[n])

```

```

379:
380:         mask_3d = combined_mask.unsqueeze(0).expand(height_voxels, -1, -1)
381:
382:         # Sanitize final mask before assignment
383:         mask_3d = _sanitize_tensor(mask_3d, default_value=0.0, name=f"final_mask_3d_fast_b{b}")
384:         voxels[b, :height_voxels] = mask_3d
385:
386:     # Final sanitization of output
387:     voxels = _sanitize_tensor(voxels, default_value=0.0, name="output_voxels_fast")
388:     return voxels

```

■ File: models\heads.py

```

=====
1: """
2: Multi-task prediction heads for the Neural-Geometric 3D Model Generator
3: """
4:
5: import torch
6: import torch.nn as nn
7: import torch.nn.functional as F
8:
9:
10: class SegmentationHead(nn.Module):
11:     """Semantic segmentation head with multi-scale fusion"""
12:
13:     def __init__(self, feature_dim=512, num_classes=5, dropout=0.1):
14:         super().__init__()
15:
16:         # Multi-scale fusion
17:         self.fusion = nn.Sequential(
18:             nn.Conv2d(feature_dim * 4, feature_dim, 3, 1, 1),
19:             nn.BatchNorm2d(feature_dim),
20:             nn.ReLU(),
21:             nn.Dropout2d(dropout),
22:         )
23:
24:         # Segmentation decoder
25:         self.decoder = nn.Sequential(
26:             nn.Conv2d(feature_dim, feature_dim // 2, 3, 1, 1),
27:             nn.BatchNorm2d(feature_dim // 2),
28:             nn.ReLU(),
29:             nn.Conv2d(feature_dim // 2, feature_dim // 4, 3, 1, 1),
30:             nn.BatchNorm2d(feature_dim // 4),
31:             nn.ReLU(),
32:             nn.Conv2d(feature_dim // 4, num_classes, 1),
33:         )
34:
35:     def forward(self, features):
36:         # Fuse multi-scale features
37:         p1, p2, p3, p4 = features["p1"], features["p2"], features["p3"], features["p4"]
38:
39:         # Upsample all to p1 resolution
40:         p2_up = F.interpolate(
41:             p2, size=p1.shape[-2:], mode="bilinear", align_corners=False
42:         )
43:         p3_up = F.interpolate(
44:             p3, size=p1.shape[-2:], mode="bilinear", align_corners=False
45:         )
46:         p4_up = F.interpolate(
47:             p4, size=p1.shape[-2:], mode="bilinear", align_corners=False
48:         )
49:
50:         fused = torch.cat([p1, p2_up, p3_up, p4_up], dim=1)
51:         fused = self.fusion(fused)
52:
53:         # Final segmentation
54:         seg = self.decoder(fused)
55:         return F.interpolate(seg, scale_factor=4, mode="bilinear", align_corners=False)
56:
57:
58: class AttributeHead(nn.Module):

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59:     """Attribute regression head for geometric parameters"""
60:
61:     def __init__(self, feature_dim=512, num_attributes=6, dropout=0.2):
62:         super().__init__()
63:
64:         self.regressor = nn.Sequential(
65:             nn.Linear(feature_dim, feature_dim),
66:             nn.ReLU(),
67:             nn.Dropout(dropout),
68:             nn.Linear(feature_dim, feature_dim // 2),
69:             nn.ReLU(),
70:             nn.Dropout(dropout),
71:             nn.Linear(feature_dim // 2, num_attributes),
72:             nn.Sigmoid(), # Output in [0,1] range
73:         )
74:
75:     def forward(self, global_features):
76:         return self.regressor(global_features)
77:
78:
79: class SDFHead(nn.Module):
80:     """Signed Distance Field prediction for sharp boundaries"""
81:
82:     def __init__(self, feature_dim=512, dropout=0.1):
83:         super().__init__()
84:
85:         self.sdf_decoder = nn.Sequential(
86:             nn.Conv2d(feature_dim, feature_dim // 2, 3, 1, 1),
87:             nn.BatchNorm2d(feature_dim // 2),
88:             nn.ReLU(),
89:             nn.Dropout2d(dropout),
90:             nn.Conv2d(feature_dim // 2, feature_dim // 4, 3, 1, 1),
91:             nn.BatchNorm2d(feature_dim // 4),
92:             nn.ReLU(),
93:             nn.Conv2d(feature_dim // 4, 1, 1),
94:             nn.Tanh(), # SDF in [-1, 1]
95:         )
96:
97:     def forward(self, features):
98:         # Use highest resolution features
99:         p1 = features["p1"]
100:         sdf = self.sdf_decoder(p1)
101:         return F.interpolate(sdf, scale_factor=4, mode="bilinear", align_corners=False)

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File: models\model.py

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1: """
2: Advanced loss functions for multi-task training with dynamic weighting
3: Enhanced with cross-modal consistency, graph constraints, and GradNorm
4: Modified to support conditional geometric losses via run_full_geometric flag
5: """
6: import torch
7: import torch.nn as nn
8: import torch.nn.functional as F
9: from .encoder import MultiScaleEncoder
10: from .heads import SegmentationHead, AttributeHead, SDFHead
11: from .dvx import DifferentiableVectorization
12: from .extrusion import DifferentiableExtrusion
13:
14:
15: class L2Normalize(nn.Module):
16:     """L2 normalization layer"""
17:
18:     def __init__(self, dim=1):
19:         super().__init__()
20:         self.dim = dim
21:
22:     def forward(self, x):
23:         return F.normalize(x, p=2, dim=self.dim)
24:
25:

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26: class LatentEmbeddingHead(nn.Module):
27:     """Auxiliary head for cross-modal latent consistency"""
28:
29:     def __init__(self, feature_dim: int, embedding_dim: int = 256):
30:         super().__init__()
31:         self.embedding_dim = embedding_dim
32:
33:         # 2D embedding path
34:         self.embedding_2d = nn.Sequential(
35:             nn.AdaptiveAvgPool2d((1, 1)),
36:             nn.Flatten(),
37:             nn.Linear(feature_dim, embedding_dim * 2),
38:             nn.ReLU(),
39:             nn.Dropout(0.1),
40:             nn.Linear(embedding_dim * 2, embedding_dim),
41:             L2Normalize(dim=1), # L2 normalize for cosine similarity
42:         )
43:
44:         # 3D embedding path (from voxel features)
45:         self.embedding_3d = nn.Sequential(
46:             nn.AdaptiveAvgPool3d((1, 1, 1)),
47:             nn.Flatten(),
48:             nn.Linear(feature_dim, embedding_dim * 2),
49:             nn.ReLU(),
50:             nn.Dropout(0.1),
51:             nn.Linear(embedding_dim * 2, embedding_dim),
52:             L2Normalize(dim=1),
53:         )
54:
55:     def forward(
56:         self, features_2d: torch.Tensor, features_3d: torch.Tensor = None
57:     ) -> tuple:
58:         """
59:         Generate 2D and 3D embeddings for consistency loss
60:
61:         Args:
62:             features_2d: [B, C, H, W] - 2D feature maps
63:             features_3d: [B, C, D, H, W] - 3D feature maps (optional)
64:
65:         Returns:
66:             tuple: (embedding_2d, embedding_3d)
67:         """
68:         # 2D embedding
69:         emb_2d = self.embedding_2d(features_2d)
70:
71:         # 3D embedding (if available, otherwise use 2D features reshaped)
72:         if features_3d is not None:
73:             emb_3d = self.embedding_3d(features_3d)
74:         else:
75:             # Create pseudo-3D from 2D features
76:             B, C, H, W = features_2d.shape
77:             pseudo_3d = features_2d.unsqueeze(2).expand(
78:                 B, C, 4, H, W
79:             ) # Duplicate across depth
80:             emb_3d = self.embedding_3d(pseudo_3d)
81:
82:         return emb_2d, emb_3d
83:
84:
85: class GraphStructureHead(nn.Module):
86:     """Head for predicting graph structure (room connectivity)"""
87:
88:     def __init__(self, feature_dim: int, max_rooms: int = 10):
89:         super().__init__()
90:         self.max_rooms = max_rooms
91:
92:         # Room detection branch
93:         self.room_detector = nn.Sequential(
94:             nn.Conv2d(feature_dim, feature_dim // 2, 3, padding=1),
95:             nn.ReLU(),
96:             nn.Conv2d(feature_dim // 2, max_rooms, 3, padding=1),
97:             nn.Sigmoid(), # Room probability maps
98:         )

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99:
100:     # Room feature extractor
101:     self.room_features = nn.Sequential(
102:         nn.AdaptiveAvgPool2d((8, 8)), # Pool to fixed size
103:         nn.Flatten(),
104:         nn.Linear(feature_dim * 64, 256),
105:         nn.ReLU(),
106:         nn.Linear(256, 128), # Room feature vectors
107:     )
108:
109:     # Adjacency predictor
110:     self.adjacency_net = nn.Sequential(
111:         nn.Linear(128 * 2, 64), # Pairwise room features
112:         nn.ReLU(),
113:         nn.Linear(64, 32),
114:         nn.ReLU(),
115:         nn.Linear(32, 1),
116:         nn.Sigmoid(), # Adjacency probability
117:     )
118:
119: def forward(self, features: torch.Tensor) -> dict:
120:     """
121:     Predict room graph structure
122:
123:     Args:
124:         features: [B, C, H, W] - Feature maps
125:
126:     Returns:
127:         dict with 'room_maps', 'room_features', 'adjacency_matrix'
128:     """
129:     B = features.shape[0]
130:
131:     # Detect room probability maps
132:     room_maps = self.room_detector(features) # [B, max_rooms, H, W]
133:
134:     # Extract room features
135:     room_feats = self.room_features(features) # [B, 128]
136:
137:     # Create adjacency matrix for all room pairs
138:     adjacency_matrices = []
139:
140:     for b in range(B):
141:         # Get room features for this batch item
142:         feat_b = room_feats[b : b + 1] # [1, 128]
143:
144:         # Create pairwise combinations
145:         adj_matrix = torch.zeros(
146:             (self.max_rooms, self.max_rooms), device=features.device
147:         )
148:
149:         for i in range(self.max_rooms):
150:             for j in range(i + 1, self.max_rooms):
151:                 # Concatenate features for room pair
152:                 pair_feat = torch.cat([feat_b, feat_b], dim=1) # [1, 256]
153:
154:                 # Predict adjacency
155:                 adj_prob = self.adjacency_net(pair_feat) # [1, 1]
156:
157:                 # Fill symmetric matrix
158:                 adj_matrix[i, j] = adj_prob.squeeze()
159:                 adj_matrix[j, i] = adj_prob.squeeze()
160:
161:             adjacency_matrices.append(adj_matrix)
162:
163:     return {
164:         "room_maps": room_maps,
165:         "room_features": room_feats,
166:         "adjacency_matrices": torch.stack(adjacency_matrices),
167:     }
168:
169:
170: class NeuralGeometric3DGenerator(nn.Module):
171:     """

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172:     Enhanced neural-geometric system with auxiliary heads for novel training strategies:
173:     - Cross-modal latent consistency
174:     - Graph structure prediction
175:     - Multi-view embeddings for dynamic curriculum
176:     - Conditional geometric computation via run_full_geometric flag
177:     """
178:
179:     def __init__(
180:         self,
181:         input_channels=3,
182:         num_classes=5,
183:         feature_dim=512,
184:         num_attributes=6,
185:         voxel_size=64,
186:         max_polygons=20,
187:         max_points=50,
188:         use_latent_consistency=True,
189:         use_graph_constraints=True,
190:         latent_embedding_dim=256,
191:     ):
192:         super().__init__()
193:
194:         # Store configuration
195:         self.use_latent_consistency = use_latent_consistency
196:         self.use_graph_constraints = use_graph_constraints
197:         self.feature_dim = feature_dim
198:
199:         # Core components
200:         self.encoder = MultiScaleEncoder(input_channels, feature_dim)
201:         self.seg_head = SegmentationHead(feature_dim, num_classes)
202:         self.attr_head = AttributeHead(feature_dim, num_attributes)
203:         self.sdf_head = SDFHead(feature_dim)
204:         self.dvx = DifferentiableVectorization(max_polygons, max_points, feature_dim)
205:         self.extrusion = DifferentiableExtrusion(voxel_size)
206:
207:         # NEW: Auxiliary heads for novel training strategies
208:         if use_latent_consistency:
209:             self.latent_head = LatentEmbeddingHead(feature_dim, latent_embedding_dim)
210:
211:         if use_graph_constraints:
212:             self.graph_head = GraphStructureHead(feature_dim)
213:
214:         # Enhanced feature processing for multi-stage training
215:         self.feature_enhancer = nn.Sequential(
216:             nn.Conv2d(feature_dim, feature_dim, 3, padding=1),
217:             nn.GroupNorm(32, feature_dim),
218:             nn.ReLU(),
219:             nn.Conv2d(feature_dim, feature_dim, 3, padding=1),
220:             nn.GroupNorm(32, feature_dim),
221:         )
222:
223:         # lazy-created 3d voxel processor will be attached on first use
224:         self._voxel_processor = None
225:
226:     def _select_spatial_feature(self, features):
227:         """
228:         Given encoder output (dict or tensor), select a spatial 4-D feature map
229:         Prefer high-resolution feature maps (p1) and avoid selecting 'global' vector.
230:         """
231:         # If encoder returned a tensor already, make sure it's 4D
232:         if not isinstance(features, dict):
233:             if features.dim() == 4:
234:                 return features
235:             else:
236:                 raise ValueError(
237:                     f"Encoder returned a tensor with shape {tuple(features.shape)}; "
238:                     "expected a 4D feature map [B, C, H, W]."
239:                 )
240:
241:         # Encoder returned dict: prefer p1,p2,p3,p4,high_res,out,main but NEVER 'global'
242:         preferred_keys = ["p1", "p2", "p3", "p4", "high_res", "out", "main"]
243:         for k in preferred_keys:
244:             if k in features:

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245:         candidate = features[k]
246:         if isinstance(candidate, torch.Tensor) and candidate.dim() == 4:
247:             return candidate
248:
249:     # As a last resort, scan dict values for the first 4D tensor that isn't 'global'
250:     for k, v in features.items():
251:         if k == "global":
252:             continue
253:         if isinstance(v, torch.Tensor) and v.dim() == 4:
254:             return v
255:
256:     # If nothing found, raise informative error rather than silently picking wrong shape
257:     raise RuntimeError(
258:         "No spatial 4D feature map found in encoder output. Encoder returned keys: "
259:         f"{list(features.keys())}. Ensure encoder provides at least one [B,C,H,W] tensor "
260:         "under keys like 'pl', 'p2', 'p3', 'p4', 'out', or 'high_res'."
261:     )
262:
263: def forward(self, image, run_full_geometric=True, return_aux=True):
264:     """
265:     Enhanced forward pass with auxiliary outputs and conditional geometric computation
266:
267:     Args:
268:         image: [B, C, H, W] input images
269:         run_full_geometric: Whether to run heavy DVX and extrusion computations
270:         return_aux: Whether to compute auxiliary outputs
271:
272:     Returns:
273:         dict with predictions, conditionally including geometric outputs
274:     """
275:     # Multi-scale feature extraction
276:     features = self.encoder(image)
277:
278:     # Enhance features
279:     spatial_feat = self._select_spatial_feature(features)
280:     enhanced_features = self.feature_enhancer(spatial_feat)
281:
282:     # keep structured features dict for heads that expect multi-scale inputs
283:     if isinstance(features, dict):
284:         features["enhanced"] = enhanced_features
285:         main_features = enhanced_features
286:     else:
287:         features = {"main": enhanced_features, "enhanced": enhanced_features}
288:         main_features = enhanced_features
289:
290:     # Core predictions (always computed - these are fast)
291:     segmentation = self.seg_head(features)
292:     attributes = self.attr_head(
293:         features.get("global")
294:         if isinstance(features, dict) and "global" in features
295:         else main_features.mean(dim=[2, 3])
296:     )
297:     sdf = self.sdf_head(features)
298:
299:     # Base outputs
300:     outputs = {
301:         "segmentation": segmentation,
302:         "attributes": attributes,
303:         "sdf": sdf,
304:         "features": features,
305:     }
306:
307:     # Conditional geometric computation (heavy operations)
308:     if run_full_geometric:
309:         # DVX polygon fitting
310:         dvx_output = self.dvx(features, segmentation)
311:         polygons = dvx_output.get("polygons", None)
312:         validity = dvx_output.get("validity", None)
313:
314:         # 3D extrusion (defensive: ensure inputs exist)
315:         try:
316:             voxels_pred = self.extrusion(polygons, attributes, validity)
317:         except Exception as e:

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318:         # Log or print a helpful message for debugging; avoid crashing training
319:         # (Replace print with logger if you have one)
320:         print(f"[Warning] extrusion failed: {e}")
321:         voxels_pred = None
322:
323:     # Add geometric outputs
324:     outputs.update({
325:         "polygons": polygons,
326:         "polygon_validity": validity,
327:         "voxels_pred": voxels_pred,
328:     })
329:
330:     # NEW: Auxiliary outputs for novel training strategies (only when geometric is enabled)
331:     if return_aux:
332:         # Cross-modal consistency embeddings
333:         if self.use_latent_consistency:
334:             if voxels_pred is not None:
335:                 voxel_features = self._create_3d_features_from_voxels(voxels_pred)
336:                 latent_2d, latent_3d = self.latent_head(main_features, voxel_features)
337:             else:
338:                 # Fall back to pseudo-3D built from 2D features if voxels not available
339:                 latent_2d, latent_3d = self.latent_head(main_features, None)
340:             outputs["latent_2d_embedding"] = latent_2d
341:             outputs["latent_3d_embedding"] = latent_3d
342:         else:
343:             # Geometric path explicitly skipped for this stage
344:             outputs.update({
345:                 "polygons": None,
346:                 "polygon_validity": None,
347:                 "voxels_pred": None,
348:             })
349:
350:     # Still compute some auxiliary outputs that don't depend on geometry
351:     if return_aux and self.use_latent_consistency:
352:         # Use pseudo-3D features for 2D-only consistency inside latent head
353:         latent_2d, latent_3d = self.latent_head(main_features, None)
354:         outputs["latent_2d_embedding"] = latent_2d
355:         outputs["latent_3d_embedding"] = latent_3d
356:
357:     # Graph structure predictions (independent of geometric computation)
358:     if return_aux and self.use_graph_constraints:
359:         graph_output = self.graph_head(main_features)
360:         outputs.update(graph_output)
361:
362:     return outputs
363:
364: def get_latent_embeddings(self, image):
365:     """
366:     Convenience method to get just the latent embeddings
367:     Used by trainer for consistency loss
368:     """
369:     if not self.use_latent_consistency:
370:         return None, None
371:
372:     with torch.no_grad():
373:         features = self.encoder(image)
374:         spatial_feat = self._select_spatial_feature(features)
375:         main_features = self.feature_enhancer(spatial_feat)
376:
377:         # Quick forward to get segmentation/attributes
378:         segmentation = self.seg_head(features)
379:         attributes = self.attr_head(
380:             features.get("global")
381:             if isinstance(features, dict) and "global" in features
382:             else main_features.mean(dim=[2, 3])
383:         )
384:
385:         # Attempt DVX + extrusion, but be defensive (may be expensive)
386:         dvx_output = self.dvx(features, segmentation)
387:         polygons = dvx_output.get("polygons", None)
388:         validity = dvx_output.get("validity", None)
389:
390:     try:

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391:         voxels_pred = self.extrusion(polygons, attributes, validity)
392:     except Exception as e:
393:         print(f"[Warning] get_latent_embeddings: extrusion failed: {e}")
394:         voxels_pred = None
395:
396:     # If voxels not available, latent_head will fall back to pseudo-3D
397:     if voxels_pred is not None:
398:         voxel_features = self._create_3d_features_from_voxels(voxels_pred)
399:     else:
400:         voxel_features = None
401:
402:     return self.latent_head(main_features, voxel_features)
403:
404: def _create_3d_features_from_voxels(self, voxels):
405:     """
406:     Create 3D feature representation from voxel predictions
407:
408:     Args:
409:         voxels: [B, D, H, W] voxel predictions
410:
411:     Returns:
412:         [B, C, D, H, W] 3D features
413:     """
414:     # Defensive check
415:     if voxels is None:
416:         raise ValueError(
417:             "Received voxels=None in _create_3d_features_from_voxels(). "
418:             "This indicates that the geometric pipeline was skipped or extrusion failed. "
419:             "Call this method only when voxels are available, or use latent_head(..., None) to "
420:             "compute pseudo-3D features from 2D."
421:         )
422:
423:     # Ensure expected shape
424:     if voxels.dim() != 4:
425:         raise ValueError(f"voxels must have shape [B,D,H,W], got {tuple(voxels.shape)}")
426:
427:     B, D, H, W = voxels.shape
428:
429:     # Expand voxels to have feature channels
430:     # Simple approach: repeat voxel values across feature dimension
431:     rep_ch = max(1, self.feature_dim // 4)
432:     voxel_features = voxels.unsqueeze(1).expand(B, rep_ch, D, H, W).contiguous()
433:
434:     # Add some learned 3D processing
435:     if self._voxel_processor is None:
436:         # Build with correct device
437:         device = voxels.device
438:         self._voxel_processor = nn.Sequential(
439:             nn.Conv3d(rep_ch, max(rep_ch, self.feature_dim // 2), 3, padding=1),
440:             nn.ReLU(),
441:             nn.Conv3d(max(rep_ch, self.feature_dim // 2), self.feature_dim, 3, padding=1),
442:         ).to(device)
443:
444:     return self._voxel_processor(voxel_features)
445:
446: def get_stage_parameters(self, stage: int):
447:     """
448:     Get parameters for specific training stage
449:     Useful for stage-specific optimization
450:     """
451:     if stage == 1:
452:         # Stage 1: 2D components only
453:         params = []
454:         params.extend(list(self.encoder.parameters()))
455:         params.extend(list(self.seg_head.parameters()))
456:         params.extend(list(self.attr_head.parameters()))
457:         params.extend(list(self.sdf_head.parameters()))
458:         params.extend(list(self.feature_enhancer.parameters()))
459:
460:         if self.use_latent_consistency:
461:             params.extend(list(self.latent_head.parameters()))
462:
463:     elif stage == 2:

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464:         # Stage 2: DVX components
465:         params = list(self.dvx.parameters())
466:
467:     else: # stage == 3
468:         # Stage 3: All parameters
469:         params = list(self.parameters())
470:
471:     return params
472:
473: def freeze_stage_parameters(self, stages_to_freeze: list):
474:     """
475:     Freeze parameters for specific stages
476:
477:     Args:
478:         stages_to_freeze: List of stage numbers to freeze
479:     """
480:     for stage in stages_to_freeze:
481:         stage_params = self.get_stage_parameters(stage)
482:         for param in stage_params:
483:             param.requires_grad = False
484:
485: def unfreeze_stage_parameters(self, stages_to_unfreeze: list):
486:     """
487:     Unfreeze parameters for specific stages
488:
489:     Args:
490:         stages_to_unfreeze: List of stage numbers to unfreeze
491:     """
492:     for stage in stages_to_unfreeze:
493:         stage_params = self.get_stage_parameters(stage)
494:         for param in stage_params:
495:             param.requires_grad = True
496:
497: def get_curriculum_metrics(self):
498:     """
499:     Get metrics useful for curriculum learning decisions
500:     """
501:     metrics = {}
502:
503:     # Parameter counts per stage
504:     for stage in [1, 2, 3]:
505:         stage_params = self.get_stage_parameters(stage)
506:         metrics[f"stage_{stage}_params"] = sum(p.numel() for p in stage_params)
507:
508:     # Feature dimensions
509:     metrics["feature_dim"] = self.feature_dim
510:     metrics["has_latent_consistency"] = self.use_latent_consistency
511:     metrics["has_graph_constraints"] = self.use_graph_constraints
512:
513:     return metrics

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File: train.py

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=====
1: """
2: Enhanced training script for the Neural-Geometric 3D Model Generator
3: Implements novel training strategies: dynamic curriculum, adaptive weighting, cross-modal
  + consistency
4: """
5:
6: import argparse
7: import torch
8: from torch.utils.data import DataLoader
9: from pathlib import Path
10: import json
11: import matplotlib.pyplot as plt
12: import numpy as np
13:
14: from dataset import AdvancedFloorPlanDataset
15: from models.model import NeuralGeometric3DGenerator
16: from training.trainer import AdaptiveMultiStageTrainer, MultiStageTrainer
17: from utils.visualization import plot_training_history, plot_curriculum_analysis

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18: from config import (
19:     DEFAULT_DATA_CONFIG,
20:     DEFAULT_MODEL_CONFIG,
21:     DEFAULT_TRAINING_CONFIG,
22:     DEFAULT_LOSS_CONFIG,
23:     TrainingConfig,
24:     CurriculumConfig
25: )
26:
27:
28: def create_enhanced_config(args):
29:     """Create enhanced training configuration with novel strategies"""
30:     config = TrainingConfig()
31:
32:     # Basic settings
33:     config.device = args.device or ("cuda" if torch.cuda.is_available() else "cpu")
34:
35:     # Dynamic curriculum settings
36:     if args.dynamic_curriculum:
37:         config.curriculum = CurriculumConfig()
38:         config.curriculum.use_dynamic_curriculum = True
39:         config.curriculum.stage_switch_patience = args.patience
40:         config.curriculum.min_improvement_threshold = args.min_improvement
41:
42:         # Adjust epoch limits for dynamic training
43:         config.max_stage1_epochs = args.max_stage1_epochs
44:         config.max_stage2_epochs = args.max_stage2_epochs
45:         config.max_stage3_epochs = args.max_stage3_epochs
46:
47:         print("Dynamic curriculum learning enabled")
48:         print(f" Stage switch patience: {config.curriculum.stage_switch_patience}")
49:         print(f" Min improvement threshold: {config.curriculum.min_improvement_threshold}")
50:     else:
51:         # Disable dynamic curriculum for traditional training
52:         config.curriculum.use_dynamic_curriculum = False
53:         print("Using traditional fixed-epoch training")
54:
55:     # GradNorm dynamic weighting
56:     if args.gradnorm:
57:         config.curriculum.use_gradnorm = True
58:         config.curriculum.gradnorm_alpha = args.gradnorm_alpha
59:         config.curriculum.gradnorm_update_freq = args.gradnorm_freq
60:         print(f"GradNorm dynamic weighting enabled (alpha={args.gradnorm_alpha})")
61:
62:     # Topology-aware scheduling
63:     if args.topology_schedule != "static":
64:         config.curriculum.topology_schedule = args.topology_schedule
65:         config.curriculum.topology_start_weight = args.topology_start
66:         config.curriculum.topology_end_weight = args.topology_end
67:         print(f"Topology-aware scheduling: {args.topology_schedule}")
68:         print(f" Weights: {args.topology_start} -> {args.topology_end}")
69:
70:     return config
71:
72:
73: def create_enhanced_model(args):
74:     """Create enhanced model with auxiliary heads"""
75:     model = NeuralGeometric3DGenerator(
76:         input_channels=args.input_channels,
77:         num_classes=args.num_classes,
78:         feature_dim=args.feature_dim,
79:         num_attributes=args.num_attributes,
80:         voxel_size=args.voxel_size,
81:         max_polygons=args.max_polygons,
82:         max_points=args.max_points,
83:         use_latent_consistency=args.latent_consistency,
84:         use_graph_constraints=args.graph_constraints,
85:         latent_embedding_dim=args.embedding_dim
86:     )
87:
88:     print(f"Enhanced model created:")
89:     print(f" Feature dim: {args.feature_dim}")
90:     print(f" Latent consistency: {args.latent_consistency}")

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91:     print(f" Graph constraints: {args.graph_constraints}")
92:
93:     # Print parameter counts
94:     total_params = sum(p.numel() for p in model.parameters())
95:     trainable_params = sum(p.numel() for p in model.parameters() if p.requires_grad)
96:     print(f" Total parameters: {total_params:,}")
97:     print(f" Trainable parameters: {trainable_params:,}")
98:
99:     return model
100:
101:
102: def visualize_training_results(history, output_dir):
103:     """Create comprehensive training visualizations"""
104:     output_dir = Path(output_dir)
105:     output_dir.mkdir(exist_ok=True)
106:
107:     # Traditional loss curves
108:     plot_training_history(history, save_path=str(output_dir / "training_history.png"))
109:
110:     # Novel curriculum analysis plots
111:     if "stage_transitions" in history and history["stage_transitions"]:
112:         plot_curriculum_analysis(history, save_path=str(output_dir / "curriculum_analysis.png"))
113:
114:     # Dynamic weight evolution
115:     if "dynamic_weights" in history and history["dynamic_weights"]:
116:         plt.figure(figsize=(12, 8))
117:
118:         # Extract weight evolution data
119:         epochs = [entry["epoch"] for entry in history["dynamic_weights"]]
120:         weight_names = list(history["dynamic_weights"][0]["weights"].keys())
121:
122:         for weight_name in weight_names:
123:             weights = [entry["weights"].get(weight_name, 0) for entry in history["dynamic_weights"]]
124:             if any(w > 0.001 for w in weights): # Only plot significant weights
125:                 plt.plot(epochs, weights, label=weight_name, linewidth=2)
126:
127:             plt.xlabel("Global Epoch")
128:             plt.ylabel("Loss Weight")
129:             plt.title("Dynamic Loss Weight Evolution")
130:             plt.legend()
131:             plt.grid(True, alpha=0.3)
132:             plt.tight_layout()
133:             plt.savefig(output_dir / "weight_evolution.png", dpi=300)
134:             plt.close()
135:
136:     # Component loss breakdown
137:     fig, axes = plt.subplots(1, 3, figsize=(18, 5))
138:     stage_names = ["stage1", "stage2", "stage3"]
139:
140:     for idx, stage_name in enumerate(stage_names):
141:         if stage_name in history and "component_losses" in history[stage_name]:
142:             component_data = history[stage_name]["component_losses"]
143:             if component_data:
144:                 # Get component names from first entry
145:                 component_names = list(component_data[0].keys())
146:
147:                 for comp_name in component_names:
148:                     if comp_name in ['seg', 'dice', 'polygon', 'voxel', 'topology',
149:                                     'latent_consistency', 'graph']:
150:                         values = [entry.get(comp_name, 0) for entry in component_data]
151:                         if any(v > 0.001 for v in values): # Only plot significant losses
152:                             axes[idx].plot(values, label=comp_name, linewidth=2)
153:
154:                     axes[idx].set_title(f"{stage_name.upper()} Component Losses")
155:                     axes[idx].set_xlabel("Epoch")
156:                     axes[idx].set_ylabel("Loss Value")
157:                     axes[idx].legend()
158:                     axes[idx].grid(True, alpha=0.3)
159:
160:     plt.tight_layout()
161:     plt.savefig(output_dir / "component_losses.png", dpi=300)
162:     plt.close()
163:

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164:     print(f"Training visualizations saved to {output_dir}")
165:
166:
167: def save_training_summary(history, config, output_dir):
168:     """Save comprehensive training summary"""
169:     output_dir = Path(output_dir)
170:
171:     summary = {
172:         "training_config": {
173:             "dynamic_curriculum": config.curriculum.use_dynamic_curriculum,
174:             "gradnorm_enabled": config.curriculum.use_gradnorm,
175:             "topology_schedule": config.curriculum.topology_schedule,
176:             "max_epochs": [config.max_stage1_epochs, config.max_stage2_epochs,
+                 config.max_stage3_epochs]
177:         },
178:         "training_results": {},
179:         "novel_strategies_summary": {}
180:     }
181:
182:     # Training results
183:     for stage_name, data in history.items():
184:         if isinstance(data, dict) and "val_loss" in data and data["val_loss"]:
185:             summary["training_results"][stage_name] = {
186:                 "final_val_loss": data["val_loss"][-1],
187:                 "best_val_loss": min(data["val_loss"]),
188:                 "epochs_trained": len(data["val_loss"])
189:             }
190:
191:     # Novel strategies summary
192:     if "stage_transitions" in history:
193:         summary["novel_strategies_summary"]["adaptive_transitions"] =
+             len(history["stage_transitions"])
194:
195:     if "dynamic_weights" in history:
196:         summary["novel_strategies_summary"]["weight_updates"] = len(history["dynamic_weights"])
197:
198:     if "curriculum_events" in history:
199:         summary["novel_strategies_summary"]["curriculum_events"] = len(history["curriculum_events"])
200:
201:     # Save as JSON
202:     with open(output_dir / "training_summary.json", 'w') as f:
203:         json.dump(summary, f, indent=2)
204:
205:     print(f"Training summary saved to {output_dir / 'training_summary.json'}")
206:
207:
208: def main():
209:     parser = argparse.ArgumentParser(description="Enhanced Neural-Geometric 3D Model Generator
+         Training")
210:
211:     # Basic arguments
212:     parser.add_argument("--data_dir", type=str, default="./data/floorplans",
213:                         help="Path to dataset directory")
214:     parser.add_argument("--batch_size", type=int, default=2, help="Batch size")
215:     parser.add_argument("--num_workers", type=int, default=4, help="Number of data workers")
216:     parser.add_argument("--device", type=str, default=None, help="Training device")
217:     parser.add_argument("--resume", type=str, default=None, help="Resume from checkpoint")
218:     parser.add_argument("--output_dir", type=str, default="./checkpoints",
219:                         help="Output directory for checkpoints")
220:
221:     # Training mode selection
222:     parser.add_argument("--training_mode", type=str, choices=["traditional", "adaptive"],
223:                         default="adaptive", help="Training mode (traditional fixed epochs vs
+         adaptive)")
224:     parser.add_argument("--stage", type=str, choices=["1", "2", "3", "all"], default="all",
225:                         help="Training stage to run (only for traditional mode)")
226:
227:     # Novel training strategies
228:     parser.add_argument("--dynamic-curriculum", action="store_true", default=True,
229:                         help="Enable adaptive stage transitioning")
230:     parser.add_argument("--patience", type=int, default=5,
231:                         help="Epochs without improvement before stage transition")
232:     parser.add_argument("--min-improvement", type=float, default=0.001,

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233:                 help="Minimum relative improvement threshold")
234:
235:     parser.add_argument("--gradnorm", action="store_true", default=True,
236:                         help="Enable GradNorm dynamic loss weighting")
237:     parser.add_argument("--gradnorm-alpha", type=float, default=0.12,
238:                         help="GradNorm restoring force parameter")
239:     parser.add_argument("--gradnorm-freq", type=int, default=5,
240:                         help="GradNorm update frequency (batches)")
241:
242:     parser.add_argument("--topology-schedule", type=str,
243:                         choices=["static", "progressive", "linear_ramp"],
244:                         default="progressive", help="Topology loss scheduling strategy")
245:     parser.add_argument("--topology-start", type=float, default=0.1,
246:                         help="Starting weight for topology loss")
247:     parser.add_argument("--topology-end", type=float, default=1.0,
248:                         help="Ending weight for topology loss")
249:
250:     # Model enhancements
251:     parser.add_argument("--latent-consistency", action="store_true", default=True,
252:                         help="Enable cross-modal latent consistency loss")
253:     parser.add_argument("--graph-constraints", action="store_true", default=True,
254:                         help="Enable graph-based topology constraints")
255:     parser.add_argument("--embedding-dim", type=int, default=256,
256:                         help="Latent embedding dimension")
257:
258:     # Model architecture
259:     parser.add_argument("--input_channels", type=int, default=3, help="Input image channels")
260:     parser.add_argument("--num_classes", type=int, default=5, help="Number of segmentation classes")
261:     parser.add_argument("--feature_dim", type=int, default=768, help="Feature dimension")
262:     parser.add_argument("--num_attributes", type=int, default=6, help="Number of attribute
+       predictions")
263:     parser.add_argument("--voxel_size", type=int, default=64, help="3D voxel grid size")
264:     parser.add_argument("--max_polygons", type=int, default=30, help="Maximum number of polygons")
265:     parser.add_argument("--max_points", type=int, default=100, help="Maximum points per polygon")
266:
267:     # Dynamic epoch limits
268:     parser.add_argument("--max-stage1-epochs", type=int, default=50, help="Max epochs for Stage 1")
269:     parser.add_argument("--max-stage2-epochs", type=int, default=35, help="Max epochs for Stage 2")
270:     parser.add_argument("--max-stage3-epochs", type=int, default=100, help="Max epochs for Stage 3")
271:
272:     parser.add_argument("--persistent_workers", action="store_true", default=False, help="Keep
+       DataLoader workers alive between epochs (requires num_workers > 0).")
273:
274:     parser.add_argument("--prefetch_factor", type=int, default=2, help="Number of batches preloaded by
+       each worker.")
275:
276:
277:     args = parser.parse_args()
278:
279:     # Setup device
280:     device = args.device or ("cuda" if torch.cuda.is_available() else "cpu")
281:     print(f"Using device: {device}")
282:
283:     import torch.backends.cudnn as cudnn
284:     if device == "cuda":
285:         cudnn.benchmark = True
286:
287:     # Create output directory
288:     output_dir = Path(args.output_dir)
289:     output_dir.mkdir(exist_ok=True)
290:
291:     # Create enhanced configuration
292:     config = create_enhanced_config(args)
293:
294:     print("\n" + "="*80)
295:     print("NEURAL-GEOMETRIC 3D MODEL GENERATOR - ENHANCED TRAINING")
296:     print("="*80)
297:     print("Novel Training Strategies Enabled:")
298:     if config.curriculum.use_dynamic_curriculum:
299:         print("? Adaptive Stage Transitioning (Dynamic Curriculum)")
300:     if config.curriculum.use_gradnorm:
301:         print("? Multi-objective Optimization with GradNorm")
302:     if config.curriculum.topology_schedule != "static":

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303:         print("? Topology-aware Loss Scheduling")
304:     if args.latent_consistency:
305:         print("? Cross-modal Latent Consistency Learning")
306:     if args.graph_constraints:
307:         print("? Graph-based Topology Constraints")
308:     print("="*80)
309:
310:     # Create datasets
311:     print("\nLoading datasets...")
312:     train_dataset = AdvancedFloorPlanDataset(
313:         args.data_dir, split="train", augment=True
314:     )
315:     val_dataset = AdvancedFloorPlanDataset(
316:         args.data_dir, split="val", augment=False
317:     )
318:
319:     print(f"Train samples: {len(train_dataset)}")
320:     print(f"Validation samples: {len(val_dataset)}")
321:
322:     if len(train_dataset) == 0:
323:         print("Error: No training samples found!")
324:         return
325:
326:     # Create data loaders
327:     train_loader = DataLoader(
328:         train_dataset,
329:         batch_size=args.batch_size,
330:         shuffle=True,
331:         num_workers=args.num_workers,
332:         pin_memory=True,
333:         drop_last=True,
334:         persistent_workers=args.persistent_workers if args.num_workers > 0 else False,
335:         prefetch_factor=args.prefetch_factor if args.num_workers > 0 else None
336:     )
337:
338:     val_loader = DataLoader(
339:         val_dataset,
340:         batch_size=max(1, args.batch_size),
341:         shuffle=False,
342:         num_workers=max(1, args.num_workers // 2),
343:         pin_memory=True,
344:         drop_last=False,
345:         persistent_workers=args.persistent_workers if args.num_workers > 0 else False,
346:         prefetch_factor=args.prefetch_factor if args.num_workers > 0 else None
347:     )
348:
349:     # Create enhanced model
350:     print("\nInitializing enhanced model...")
351:     model = create_enhanced_model(args)
352:
353:     # Create appropriate trainer
354:     if args.training_mode == "adaptive":
355:         print("\nUsing Adaptive Multi-Stage Trainer with Novel Strategies")
356:         trainer = AdaptiveMultiStageTrainer(
357:             model=model,
358:             train_loader=train_loader,
359:             val_loader=val_loader,
360:             device=device,
361:             config=config
362:         )
363:     else:
364:         print("\nUsing Traditional Multi-Stage Trainer")
365:         trainer = MultiStageTrainer(
366:             model=model,
367:             train_loader=train_loader,
368:             val_loader=val_loader,
369:             device=device,
370:             config=config
371:         )
372:
373:     # Resume from checkpoint if specified
374:     if args.resume:
375:         print(f"Resuming from checkpoint: {args.resume}")

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376:         trainer.load_checkpoint(args.resume)
377:
378:     # Run training
379:     if args.training_mode == "adaptive" or args.stage == "all":
380:         print("\nStarting adaptive multi-stage training with novel strategies...")
381:         history = trainer.train_all_stages()
382:     else:
383:         # Traditional single-stage training
384:         stage_num = int(args.stage)
385:         print(f"Training Stage {stage_num} only...")
386:         if stage_num == 1:
387:             trainer.train_stage1()
388:         elif stage_num == 2:
389:             trainer.train_stage2()
390:         elif stage_num == 3:
391:             trainer.train_stage3()
392:         history = trainer.history
393:
394:     # Save final model
395:     final_model_path = output_dir / "final_enhanced_model.pth"
396:     if hasattr(trainer, '_save_checkpoint'):
397:         trainer._save_checkpoint(str(final_model_path))
398:     print(f"Final model saved to: {final_model_path}")
399:
400:     # Create comprehensive visualizations
401:     print("\nGenerating training analysis...")
402:     visualize_training_results(history, output_dir)
403:
404:     # Save training summary
405:     save_training_summary(history, config, output_dir)
406:
407:     print(f"\n? Enhanced training completed successfully!")
408:     print(f"? Results saved to: {output_dir}")
409:     print("\nNovel contributions implemented:")
410:     print("- Dynamic curriculum learning with adaptive stage transitions")
411:     print("- Multi-objective optimization with gradient-based reweighting")
412:     print("- Topology-aware progressive constraint injection")
413:     print("- Cross-modal latent consistency learning")
414:     print("- Graph-based architectural constraint learning")
415:
416:
417: if __name__ == "__main__":
418:     main()

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File: traininglosses.py

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=====
1: """
2: Advanced loss functions for multi-task training with dynamic weighting
3: Enhanced with cross-modal consistency, graph constraints, and GradNorm
4: Modified to support conditional geometric losses via run_full_geometric flag
5: FIXED: Dynamic loss component initialization for stage transitions
6: """
7:
8: import torch
9: import torch.nn as nn
10: import torch.nn.functional as F
11: import cv2
12: import numpy as np
13: from typing import Dict, Optional, Tuple, List
14: import networkx as nx
15:
16:
17: class DynamicLossWeighter:
18:     def __init__(self, loss_names: List[str], alpha: float = 0.12, device: str = 'cuda'):
19:         self.loss_names = loss_names
20:         self.alpha = alpha
21:         self.device = device
22:
23:         # Initialize weights for all known loss components
24:         self.weights = {name: 1.0 for name in loss_names}
25:         self.initial_task_losses = {}

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26:         # Add running normalization to prevent raw magnitude issues
27:         self.running_mean_losses = {name: 0.0 for name in loss_names}
28:         self.running_std_losses = {name: 1.0 for name in loss_names} # NEW
29:         self.update_count = 0
30:
31:         print(f"[DynamicWeighter] Initialized with loss components: {loss_names}")
32:
33:     def update_weights(self, task_losses: Dict[str, torch.Tensor],
34:                       shared_parameters, update_freq: int = 10):
35:         """Update loss weights using GradNorm with stability improvements"""
36:         if self.update_count % update_freq != 0:
37:             self.update_count += 1
38:             return self.weights
39:
40:         # Initialize tracking for new loss components
41:         newly_initialized = []
42:         for name, loss in task_losses.items():
43:             if name not in self.initial_task_losses:
44:                 loss_val = loss.item() if torch.is_tensor(loss) else float(loss)
45:                 # Use log-scale initialization for stability
46:                 self.initial_task_losses[name] = max(np.log(abs(loss_val) + 1e-6), -10.0)
47:
48:                 if name not in self.weights:
49:                     self.weights[name] = 1.0
50:                 if name not in self.running_mean_losses:
51:                     self.running_mean_losses[name] = loss_val
52:                 if name not in self.running_std_losses:
53:                     self.running_std_losses[name] = max(abs(loss_val), 1e-3)
54:
55:                 newly_initialized.append(name)
56:
57:         # Update running statistics with EMA
58:         for name, loss in task_losses.items():
59:             loss_val = loss.item() if torch.is_tensor(loss) else float(loss)
60:             if name in self.running_mean_losses:
61:                 # Exponential moving average for mean and std
62:                 self.running_mean_losses[name] = 0.9 * self.running_mean_losses[name] + 0.1 *
+                 loss_val
63:
64:                 # Update running std using Welford's algorithm
65:                 delta = loss_val - self.running_mean_losses[name]
66:                 self.running_std_losses[name] = 0.9 * self.running_std_losses[name] + 0.1 *
+                 abs(delta)
67:                 self.running_std_losses[name] = max(self.running_std_losses[name], 1e-3)
68:
69:         # Calculate normalized relative decrease rates
70:         loss_ratios = {}
71:         for name, loss in task_losses.items():
72:             if name in self.initial_task_losses and self.initial_task_losses[name] > -9.0:
73:                 # Normalize current loss by running statistics
74:                 current_loss = self.running_mean_losses.get(name, loss.item())
75:                 normalized_current = current_loss / (self.running_std_losses[name] + 1e-6)
76:
77:                 initial_loss = self.initial_task_losses[name]
78:                 # Use log-space ratios for stability
79:                 loss_ratios[name] = np.exp(min(max(normalized_current - initial_loss, -5.0), 5.0))
80:
81:         if not loss_ratios:
82:             self.update_count += 1
83:             return self.weights
84:
85:         # Calculate gradient norms with improved stability
86:         grad_norms = {}
87:         for name, loss in task_losses.items():
88:             if name in loss_ratios:
89:                 if not torch.is_tensor(loss) or not loss.requires_grad:
90:                     continue
91:                 if not torch.isfinite(loss):
92:                     continue
93:
94:                 try:
95:                     grads = torch.autograd.grad(
96:                         loss, shared_parameters,

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97:             retain_graph=True, create_graph=False, allow_unused=True
98:         )
99:
100:         grad_norm_sq = 0.0
101:         valid_grads = False
102:         for grad in grads:
103:             if grad is not None and torch.isfinite(grad).all():
104:                 # Apply gradient norm stabilization
105:                 clipped_grad = torch.clamp(grad, -10.0, 10.0)
106:                 grad_norm_sq += clipped_grad.norm().item() ** 2
107:                 valid_grads = True
108:
109:         if valid_grads and grad_norm_sq > 0:
110:             # Use log-scale gradient norms
111:             grad_norms[name] = np.log(grad_norm_sq ** 0.5 + 1e-8)
112:
113:     except Exception as e:
114:         continue
115:
116:     if not grad_norms:
117:         self.update_count += 1
118:         return self.weights
119:
120:     # Normalize gradient norms
121:     mean_grad_norm = np.mean(list(grad_norms.values()))
122:
123:     # Update weights with improved stability
124:     for name in grad_norms.keys():
125:         if name in loss_ratios:
126:             # Calculate target gradient in log space
127:             target_grad_log = mean_grad_norm + self.alpha * np.log(loss_ratios[name] + 1e-8)
128:             current_grad_log = grad_norms[name]
129:
130:             # Calculate weight update with damping
131:             weight_update_log = target_grad_log - current_grad_log
132:             weight_update = np.exp(np.clip(weight_update_log, -1.0, 1.0)) # Stronger clipping
133:
134:             # Apply update with momentum and stronger constraints
135:             current_weight = self.weights.get(name, 1.0)
136:             new_weight = 0.8 * current_weight + 0.2 * weight_update # More conservative
137:             self.weights[name] = float(np.clip(new_weight, 0.1, 2.0)) # Tighter bounds
138:
139:         self.update_count += 1
140:         return self.weights
141:
142: class GraphTopologyExtractor:
143:     """Extracts graph structure from segmentation for topology constraints"""
144:
145:     @staticmethod
146:     def extract_room_graph(segmentation: torch.Tensor) -> Dict[str, torch.Tensor]:
147:         """Extract room connectivity graph from segmentation mask"""
148:         B, C, H, W = segmentation.shape
149:         device = segmentation.device
150:
151:         # Get room predictions (assume classes: 0=bg, 1=wall, 2=door, 3=window, 4=room)
152:         room_probs = F.softmax(segmentation, dim=1)
153:         room_mask = room_probs[:, 4] if C > 4 else torch.zeros((B, H, W), device=device)
154:         wall_mask = room_probs[:, 1] if C > 1 else torch.zeros((B, H, W), device=device)
155:
156:         # Simple connectivity: rooms connected if they share wall boundary
157:         adjacency_matrices = []
158:         room_features = []
159:
160:         for b in range(B):
161:             room_b = room_mask[b].detach().cpu().numpy()
162:             wall_b = wall_mask[b].detach().cpu().numpy()
163:
164:             # Find connected components (rooms)
165:             try:
166:                 from scipy import ndimage
167:                 labeled_rooms, num_rooms = ndimage.label(room_b > 0.5)
168:
169:                 # Create adjacency matrix

```

```

170:         adj_matrix = np.zeros((max(num_rooms, 1), max(num_rooms, 1)))
171:         room_centroids = []
172:
173:         for i in range(1, num_rooms + 1):
174:             room_i_mask = (labeled_rooms == i)
175:             if np.sum(room_i_mask) > 0:
176:                 centroid = ndimage.center_of_mass(room_i_mask)
177:                 room_centroids.append(centroid)
178:
179:             # Check connectivity to other rooms through walls
180:             for j in range(i + 1, num_rooms + 1):
181:                 room_j_mask = (labeled_rooms == j)
182:                 if np.sum(room_j_mask) > 0:
183:                     # Check if rooms are connected via wall adjacency
184:                     connectivity = GraphTopologyExtractor._check_room_connectivity(
185:                         room_i_mask, room_j_mask, wall_b
186:                     )
187:                     adj_matrix[i-1, j-1] = connectivity
188:                     adj_matrix[j-1, i-1] = connectivity
189:
190:             # Convert to tensor
191:             adj_tensor = torch.from_numpy(adj_matrix).float().to(device)
192:             centroids_tensor = torch.from_numpy(np.array(room_centroids) if room_centroids else
+             np.zeros((0, 2))).float().to(device)
193:
194:         except ImportError:
195:             # Fallback if scipy not available
196:             adj_tensor = torch.zeros((1, 1), device=device)
197:             centroids_tensor = torch.zeros((0, 2), device=device)
198:         except Exception as e:
199:             # General fallback for any other issues
200:             print(f"Warning: Graph extraction failed: {e}")
201:             adj_tensor = torch.zeros((1, 1), device=device)
202:             centroids_tensor = torch.zeros((0, 2), device=device)
203:
204:         adjacency_matrices.append(adj_tensor)
205:         room_features.append(centroids_tensor)
206:
207:     return {
208:         "adjacency_matrices": adjacency_matrices,
209:         "room_features": room_features
210:     }
211:
212: @staticmethod
213: def _check_room_connectivity(room1_mask, room2_mask, wall_mask):
214:     """Check if two rooms are connected through walls"""
215:     try:
216:         from scipy.ndimage import binary_dilation
217:
218:         # Dilate room masks to check wall adjacency
219:         dilated1 = binary_dilation(room1_mask, iterations=2)
220:         dilated2 = binary_dilation(room2_mask, iterations=2)
221:
222:         # Check overlap through wall areas
223:         wall_overlap = (dilated1 & dilated2) & (wall_mask > 0.3)
224:         return float(np.sum(wall_overlap) > 0)
225:     except ImportError:
226:         # Simple distance-based fallback
227:         return 0.0
228:
229:
230: class ResearchGradeLoss(nn.Module):
231:     """
232:     Multi-task loss with stage-aware dynamic weighting:
233:     - Stage 1: segmentation, dice, sdf, attributes, topology, graph
234:     - Stage 2: + polygon (DVX)
235:     - Stage 3: + voxel, latent_consistency (full geometric)
236:
237:     FIXED: Dynamic initialization handles new loss components during stage transitions
238:     """
239:
240:     def __init__(
241:         self,

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242:         seg_weight: float = 1.0,
243:         dice_weight: float = 1.0,
244:         sdf_weight: float = 0.5,
245:         attr_weight: float = 1.0,
246:         polygon_weight: float = 1.0,
247:         voxel_weight: float = 1.0,
248:         topology_weight: float = 0.5,
249:         latent_consistency_weight: float = 0.5,
250:         graph_constraint_weight: float = 0.3,
251:         enable_dynamic_weighting: bool = True,
252:         gradnorm_alpha: float = 0.12,
253:         device: str = 'cuda',
254:         weight_update_freq: int = 10,
255:         weight_momentum: float = 0.9,
256:     ):
257:         super().__init__()
258:
259:         # Store initial weights for all possible loss components
260:         self.initial_weights = {
261:             'seg': float(seg_weight),
262:             'dice': float(dice_weight),
263:             'sdf': float(sdf_weight),
264:             'attr': float(attr_weight),
265:             'polygon': float(polygon_weight),
266:             'voxel': float(voxel_weight),
267:             'topology': float(topology_weight),
268:             'latent_consistency': float(latent_consistency_weight),
269:             'graph': float(graph_constraint_weight)
270:         }
271:
272:         # Current weights (will be dynamically updated)
273:         self.weights = self.initial_weights.copy()
274:
275:         # Core losses
276:         self.ce_loss = nn.CrossEntropyLoss()
277:         self.mse_loss = nn.MSELoss()
278:         self.l1_loss = nn.L1Loss()
279:         self.cosine_loss = nn.CosineEmbeddingLoss()
280:
281:         # Dynamic weighting with all possible loss names
282:         self.enable_dynamic_weighting = enable_dynamic_weighting
283:         if enable_dynamic_weighting:
284:             all_loss_names = list(self.initial_weights.keys())
285:             self.loss_weighter = DynamicLossWeighter(
286:                 all_loss_names, alpha=gradnorm_alpha, device=device,
287:             )
288:             self.update_freq = weight_update_freq
289:             self.momentum = weight_momentum
290:             print(f"[ResearchGradeLoss] Dynamic weighting enabled for: {all_loss_names}")
291:
292:         self.device = device
293:
294:     def update_loss_weights(self, new_weights: Dict[str, float]):
295:         """Update loss weights (called by trainer for curriculum scheduling)"""
296:         for key, value in new_weights.items():
297:             if key in self.weights:
298:                 self.weights[key] = float(value)
299:
300:     def forward(self, predictions: dict, targets: dict, shared_parameters=None,
+               run_full_geometric=True):
301:         """Compute multi-task loss with proper normalization and aggregation"""
302:         # Input validation and sanitization
303:         predictions = self._sanitize_predictions(predictions)
304:         targets = self._sanitize_targets(targets)
305:
306:         device = self._get_device_from_inputs(predictions, targets)
307:         losses = {}
308:         total_loss = torch.tensor(0.0, device=device, requires_grad=True)
309:
310:         # ---- STAGE 1 LOSSES with proper scaling ----
311:         if "segmentation" in predictions and "mask" in targets:
312:             seg_pred = predictions["segmentation"]
313:             seg_target = targets["mask"].long()

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314:
315:     # Scale CE loss by number of pixels for consistency
316:     ce_loss = self.ce_loss(seg_pred, seg_target)
317:     losses["seg"] = ce_loss
318:
319:     dice_loss = self._dice_loss(seg_pred, seg_target)
320:     losses["dice"] = dice_loss
321:
322:     if "sdf" in predictions and "mask" in targets:
323:         sdf_pred = predictions["sdf"]
324:         sdf_pred = torch.clamp(sdf_pred, -1.0, 1.0)
325:         sdf_target = self._mask_to_sdf(targets["mask"])
326:         sdf_target = sdf_target.to(sdf_pred.device).type_as(sdf_pred)
327:         # Normalize SDF loss by spatial dimensions
328:         sdf_loss = self.mse_loss(sdf_pred, sdf_target)
329:         losses["sdf"] = sdf_loss
330:
331:     if "attributes" in predictions and "attributes" in targets:
332:         pred_attr = predictions["attributes"].float()
333:         tgt_attr = targets["attributes"].float().to(pred_attr.device)
334:         # Normalize attribute loss by number of attributes
335:         attr_loss = self.l1_loss(pred_attr, tgt_attr) / pred_attr.shape[-1]
336:         losses["attr"] = attr_loss
337:
338:     # Apply proper scaling to topology losses
339:     if "segmentation" in predictions:
340:         topology_loss = self._topology_loss(predictions["segmentation"])
341:         # Scale topology loss to reasonable magnitude
342:         losses["topology"] = topology_loss * 0.5
343:
344:         graph_loss = self._graph_topology_loss(predictions["segmentation"])
345:         # Graph loss is already scaled in the function above
346:         losses["graph"] = graph_loss
347:
348:     # ---- GEOMETRIC LOSSES with normalization ----
349:     if run_full_geometric:
350:         if ("polygons" in predictions and predictions["polygons"] is not None and
351:             "polygons_gt" in targets):
352:             poly_loss = self._polygon_loss(predictions, targets["polygons_gt"])
353:             # Normalize polygon loss by number of polygons and points
354:             if "polygons" in predictions and predictions["polygons"] is not None:
355:                 B, P, N, _ = predictions["polygons"].shape
356:                 poly_loss = poly_loss / (P * N) # Normalize by polygon complexity
357:                 losses["polygon"] = poly_loss
358:             else:
359:                 losses["polygon"] = torch.tensor(0.0, device=device)
360:
361:         if ("voxels_pred" in predictions and predictions["voxels_pred"] is not None and
362:             "voxels_gt" in targets):
363:             pred_vox = predictions["voxels_pred"].float()
364:             tgt_vox = targets["voxels_gt"].float().to(pred_vox.device)
365:             voxel_loss = self._voxel_iou_loss(pred_vox, tgt_vox)
366:             losses["voxel"] = voxel_loss
367:         else:
368:             losses["voxel"] = torch.tensor(0.0, device=device)
369:
370:         if ("latent_2d_embedding" in predictions and "latent_3d_embedding" in predictions and
371:             predictions["latent_2d_embedding"] is not None and
372:             predictions["latent_3d_embedding"] is not None):
373:             consistency_loss = self._latent_consistency_loss(
374:                 predictions["latent_2d_embedding"],
375:                 predictions["latent_3d_embedding"]
376:             )
377:             losses["latent_consistency"] = consistency_loss
378:         else:
379:             losses["latent_consistency"] = torch.tensor(0.0, device=device)
380:
381:     else:
382:         losses["polygon"] = torch.tensor(0.0, device=device)
383:         losses["voxel"] = torch.tensor(0.0, device=device)
384:         losses["latent_consistency"] = torch.tensor(0.0, device=device)
385:
386:     # ---- IMPROVED WEIGHTING AND AGGREGATION ----
387:     active_losses = {

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386:         name: loss for name, loss in losses.items()
387:         if isinstance(loss, torch.Tensor) and loss.requires_grad and loss.item() > 1e-8
388:     }
389:
390: if self.enable_dynamic_weighting and shared_parameters is not None and active_losses:
391:     try:
392:         dynamic_weights = self.loss_weighter.update_weights(
393:             active_losses, shared_parameters, self.update_freq
394:         )
395:
396:         # Apply weights with additional stability checks
397:         for name, loss in losses.items():
398:             if name in self.weights and isinstance(loss, torch.Tensor) and
+                 torch.isfinite(loss):
399:                 weight = dynamic_weights.get(name, self.weights[name])
400:                 # Apply weight with gradient scaling for stability
401:                 weighted_loss = weight * loss
402:                 if torch.isfinite(weighted_loss):
403:                     total_loss = total_loss + weighted_loss
404:
405:     except Exception as e:
406:         print(f"[ResearchGradeLoss] Dynamic weighting failed: {e}, falling back to static
+             weights")
407:         # Fallback to static weights
408:         for name, loss in losses.items():
409:             if name in self.weights and isinstance(loss, torch.Tensor) and
+                 torch.isfinite(loss):
410:                 total_loss = total_loss + self.weights[name] * loss
411:     else:
412:         # Static weights with stability
413:         for name, loss in losses.items():
414:             if name in self.weights and isinstance(loss, torch.Tensor) and torch.isfinite(loss):
415:                 total_loss = total_loss + self.weights[name] * loss
416:
417:     # Final loss scaling and validation
418:     total_loss = torch.clamp(total_loss, 0.0, 100.0) # Prevent explosion
419:
420:     if not torch.isfinite(total_loss):
421:         print("[ResearchGradeLoss] Warning: Non-finite total loss detected, using fallback")
422:         total_loss = torch.tensor(1.0, device=device, requires_grad=True)
423:
424:     losses["total"] = total_loss
425:     return total_loss, losses
426:
427: def __call__(self, predictions: dict, targets: dict, shared_parameters=None,
+             run_full_geometric=True):
428:     """Trainer compatibility method"""
429:     return self.forward(predictions, targets, shared_parameters, run_full_geometric)
430:
431: def _sanitize_predictions(self, predictions: dict) -> dict:
432:     """Sanitize prediction tensors"""
433:     sanitized = {}
434:     for name, tensor in predictions.items():
435:         if torch.is_tensor(tensor):
436:             if torch.isnan(tensor).any() or torch.isinf(tensor).any():
437:                 print(f"WARNING: NaN/Inf in predictions[{name}] - zeroing out")
438:                 sanitized[name] = torch.zeros_like(tensor)
439:             else:
440:                 sanitized[name] = tensor
441:         else:
442:             sanitized[name] = tensor
443:     return sanitized
444:
445: def _sanitize_targets(self, targets: dict) -> dict:
446:     """Sanitize target tensors"""
447:     sanitized = {}
448:     for name, tensor in targets.items():
449:         if torch.is_tensor(tensor):
450:             if torch.isnan(tensor).any() or torch.isinf(tensor).any():
451:                 print(f"WARNING: NaN/Inf in targets[{name}] - zeroing out")
452:                 sanitized[name] = torch.zeros_like(tensor)
453:             else:
454:                 sanitized[name] = tensor

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455:         else:
456:             sanitized[name] = tensor
457:         return sanitized
458:
459:     def _get_device_from_inputs(self, predictions, targets):
460:         """Helper to determine device from inputs"""
461:         for pred_dict in [predictions, targets]:
462:             for value in pred_dict.values():
463:                 if torch.is_tensor(value):
464:                     return value.device
465:         return self.device
466:
467:     # ---- LOSS COMPONENT IMPLEMENTATIONS ----
468:
469:     def _latent_consistency_loss(self, embedding_2d: torch.Tensor, embedding_3d: torch.Tensor) ->
+         torch.Tensor:
470:         """Cross-modal latent consistency loss"""
471:         if embedding_2d.shape != embedding_3d.shape:
472:             min_dim = min(embedding_2d.shape[-1], embedding_3d.shape[-1])
473:             embedding_2d = embedding_2d[..., :min_dim]
474:             embedding_3d = embedding_3d[..., :min_dim]
475:
476:             target = torch.ones(embedding_2d.shape[0], device=embedding_2d.device)
477:             cosine_loss = self.cosine_loss(embedding_2d, embedding_3d, target)
478:             l2_loss = F.mse_loss(embedding_2d, embedding_3d)
479:
480:             return 0.7 * cosine_loss + 0.3 * l2_loss
481:
482:     def _graph_topology_loss(self, segmentation_logits: torch.Tensor) -> torch.Tensor:
483:         """Graph-based topology constraints with proper normalization"""
484:         try:
485:             graph_data = GraphTopologyExtractor.extract_room_graph(segmentation_logits)
486:             device = segmentation_logits.device
487:
488:             total_graph_loss = torch.tensor(0.0, device=device)
489:             batch_size = segmentation_logits.shape[0]
490:             valid_batches = 0
491:
492:             for b in range(batch_size):
493:                 if b < len(graph_data["adjacency_matrices"]):
494:                     adj_matrix = graph_data["adjacency_matrices"][b]
495:                     if adj_matrix.numel() == 0:
496:                         continue
497:
498:                     # Normalize by matrix size to prevent scale explosion
499:                     matrix_size = max(adj_matrix.shape[0], 1)
500:                     norm_factor = 1.0 / (matrix_size + 1e-6)
501:
502:                     degrees = adj_matrix.sum(dim=1)
503:                     isolation_penalty = torch.exp(-degrees).mean() * norm_factor
504:
505:                     max_reasonable_connections = min(4, adj_matrix.shape[0] - 1)
506:                     over_connection_penalty = F.relu(degrees - max_reasonable_connections).mean() *
+                         norm_factor
507:
508:                     if b < len(graph_data["room_features"]) and
+                         graph_data["room_features"][b].numel() > 0:
509:                         room_features = graph_data["room_features"][b]
510:                         if room_features.shape[0] > 1:
511:                             feature_distances = torch.cdist(room_features, room_features)
512:                             # Normalize distance computation
513:                             mean_distance = feature_distances.mean()
514:                             normalized_distances = feature_distances / (mean_distance + 1e-6)
515:                             smoothness_loss = (adj_matrix * normalized_distances).sum() /
+                                 (adj_matrix.sum() + 1e-6)
516:                             smoothness_loss = smoothness_loss * norm_factor
517:                         else:
518:                             smoothness_loss = torch.tensor(0.0, device=device)
519:                     else:
520:                         smoothness_loss = torch.tensor(0.0, device=device)
521:
522:                     # Apply strong penalty scaling to keep graph loss in reasonable range
523:                     batch_graph_loss = (0.4 * isolation_penalty +

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524:         0.3 * over_connection_penalty +
525:         0.3 * smoothness_loss) * 0.1 # Scale down by 10x
526:
527:         total_graph_loss = total_graph_loss + batch_graph_loss
528:         valid_batches += 1
529:
530:         # Average over valid batches and apply final normalization
531:         if valid_batches > 0:
532:             return total_graph_loss / valid_batches
533:         else:
534:             return torch.tensor(0.0, device=segmentation_logits.device)
535:
536:     except Exception as e:
537:         return torch.tensor(0.0, device=segmentation_logits.device)
538:
539: def _dice_loss(self, pred: torch.Tensor, target: torch.Tensor, smooth: float = 1e-6) ->
+     torch.Tensor:
540:     """Dice loss implementation"""
541:     pred_soft = F.softmax(pred, dim=1)
542:     B, C = pred_soft.shape[:2]
543:
544:     dice_losses = []
545:     for c in range(C):
546:         pred_c = pred_soft[:, c, :, :]
547:         target_c = (target == c).float().to(pred_c.device)
548:         intersection = (pred_c * target_c).view(B, -1).sum(dim=1)
549:         union = pred_c.view(B, -1).sum(dim=1) + target_c.view(B, -1).sum(dim=1)
550:         dice = (2.0 * intersection + smooth) / (union + smooth)
551:         dice_losses.append((1.0 - dice).mean())
552:
553:     return torch.stack(dice_losses).mean()
554:
555: def _mask_to_sdf(self, mask: torch.Tensor) -> torch.Tensor:
556:     """Convert mask to SDF"""
557:     device = mask.device if torch.is_tensor(mask) else self.device
558:     if not torch.is_tensor(mask):
559:         mask = torch.tensor(mask, device=device)
560:
561:     B, H, W = mask.shape
562:     sdf = torch.zeros((B, 1, H, W), dtype=torch.float32, device=device)
563:
564:     for b in range(B):
565:         mask_np = mask[b].detach().cpu().numpy().astype(np.uint8)
566:         try:
567:             dist_inside = cv2.distanceTransform((mask_np > 0).astype(np.uint8), cv2.DIST_L2, 5)
568:             dist_outside = cv2.distanceTransform((mask_np == 0).astype(np.uint8), cv2.DIST_L2,
+             5)
569:             sdf_np = dist_inside.astype(np.float32) - dist_outside.astype(np.float32)
570:             sdf_np = np.tanh(sdf_np / 10.0).astype(np.float32)
571:             sdf[b, 0] = torch.from_numpy(sdf_np)
572:         except Exception:
573:             sdf[b, 0] = torch.zeros_like(mask[b].float())
574:
575:     return sdf
576:
577: def _polygon_loss(self, predictions: dict, targets: dict) -> torch.Tensor:
578:     """Polygon/DVX loss"""
579:     pred_polys = predictions.get("polygons")
580:     tgt_polys = targets.get("polygons")
581:     valid_mask = targets.get("valid_mask")
582:
583:     if pred_polys is None or tgt_polys is None:
584:         return torch.tensor(0.0, device=pred_polys.device if pred_polys is not None else
+         self.device)
585:
586:     pred_polys = pred_polys.float()
587:     tgt_polys = tgt_polys.float().to(pred_polys.device)
588:
589:     point_loss = self.mse_loss(pred_polys, tgt_polys)
590:
591:     pred_valid = predictions.get("polygon_validity")
592:     if pred_valid is None or valid_mask is None:
593:         validity_loss = torch.tensor(0.0, device=pred_polys.device)

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594:         else:
595:             pred_valid = pred_valid.float().to(pred_polys.device)
596:             valid_mask_f = valid_mask.float().to(pred_polys.device)
597:             validity_loss = self.mse_loss(pred_valid, valid_mask_f)
598:
599:             smoothness_loss = self._polygon_smoothness(pred_polys)
600:             rect_loss = self._rectilinearity_loss(pred_polys)
601:
602:             return point_loss + 0.1 * validity_loss + 0.05 * smoothness_loss + 0.1 * rect_loss
603:
604: def _polygon_smoothness(self, polygons: torch.Tensor) -> torch.Tensor:
605:     """Polygon smoothness loss"""
606:     if polygons is None or polygons.numel() == 0:
607:         return torch.tensor(0.0, device=polygons.device if polygons is not None else
+             self.device)
608:
609:     p1 = polygons
610:     p2 = torch.roll(polygons, -1, dims=2)
611:     p3 = torch.roll(polygons, -2, dims=2)
612:     curvature = torch.norm(p1 - 2.0 * p2 + p3, dim=-1)
613:     return curvature.mean()
614:
615: def _rectilinearity_loss(self, polygons: torch.Tensor) -> torch.Tensor:
616:     """Encourage axis-aligned structure"""
617:     if polygons is None or polygons.numel() == 0:
618:         return torch.tensor(0.0, device=polygons.device if polygons is not None else
+             self.device)
619:
620:     edges = torch.roll(polygons, -1, dims=2) - polygons
621:     edge_norms = torch.norm(edges, dim=-1, keepdim=True)
622:     edges_normalized = edges / (edge_norms + 1e-6)
623:
624:     edge1 = edges_normalized
625:     edge2 = torch.roll(edges_normalized, -1, dims=2)
626:
627:     cos_angles = (edge1 * edge2).sum(dim=-1)
628:     cos2 = cos_angles ** 2
629:     perp_penalty = cos2
630:     parallel_penalty = (cos2 - 1.0) ** 2
631:     angle_penalty = torch.minimum(perp_penalty, parallel_penalty)
632:     return angle_penalty.mean()
633:
634: def _voxel_iou_loss(self, pred_voxels: torch.Tensor, target_voxels: torch.Tensor) ->
+     torch.Tensor:
635:     """3D voxel IoU loss"""
636:     pred_prob = torch.sigmoid(torch.clamp(pred_voxels, -10.0, 10.0))
637:     target = target_voxels.float().to(pred_prob.device)
638:
639:     intersection = (pred_prob * target).view(pred_prob.shape[0], -1).sum(dim=1)
640:     union = (pred_prob.view(pred_prob.shape[0], -1).sum(dim=1) +
641:             target.view(target.shape[0], -1).sum(dim=1) - intersection)
642:
643:     iou = (intersection + 1e-6) / (union + 1e-6)
644:     return (1.0 - iou).mean()
645:
646: def _topology_loss(self, segmentation_logits: torch.Tensor) -> torch.Tensor:
647:     """Traditional topology loss"""
648:     seg_soft = F.softmax(segmentation_logits, dim=1)
649:     C = seg_soft.shape[1]
650:     device = seg_soft.device
651:
652:     walls = seg_soft[:, 1] if C > 1 else torch.zeros_like(seg_soft[:, 0])
653:     doors = seg_soft[:, 2] if C > 2 else torch.zeros_like(walls)
654:     windows = seg_soft[:, 3] if C > 3 else torch.zeros_like(walls)
655:
656:     door_wall_overlap = doors * walls
657:     window_wall_overlap = windows * walls
658:
659:     door_penalty = torch.maximum(doors - door_wall_overlap, torch.zeros_like(doors))
660:     window_penalty = torch.maximum(windows - window_wall_overlap, torch.zeros_like(windows))
661:
662:     connectivity_loss = self._connectivity_loss(walls)
663:

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664:         return door_penalty.mean() + window_penalty.mean() + 0.1 * connectivity_loss
665:
666:     def _connectivity_loss(self, wall_prob: torch.Tensor) -> torch.Tensor:
667:         """Connectivity loss for walls"""
668:         if wall_prob is None or wall_prob.numel() == 0:
669:             return torch.tensor(0.0, device=wall_prob.device if wall_prob is not None else
+                 self.device)
670:
671:         kernel = torch.ones((1, 1, 3, 3), device=wall_prob.device, dtype=wall_prob.dtype) / 9.0
672:         neighbors = F.conv2d(wall_prob.unsqueeze(1), kernel, padding=1).squeeze(1)
673:
674:         isolation_penalty = wall_prob * torch.exp(-neighbors)
675:         return isolation_penalty.mean()
676:
677:
678: class LossScheduler:
679:     """Manages curriculum-based loss weight scheduling"""
680:
681:     def __init__(self, config):
682:         self.config = config
683:         self.loss_schedules = config.loss_schedule
684:
685:     def get_scheduled_weights(self, current_stage: int, current_epoch: int,
686:                               stage_epoch: int, total_stage_epochs: int,
687:                               base_weights: Dict[str, float]) -> Dict[str, float]:
688:         """Calculate loss weights based on curriculum schedule"""
689:         scheduled_weights = base_weights.copy()
690:
691:         for loss_name, schedule_type in self.loss_schedules.items():
692:             if loss_name not in scheduled_weights:
693:                 continue
694:
695:             base_weight = scheduled_weights[loss_name]
696:
697:             if schedule_type == "static":
698:                 continue
699:
700:             elif schedule_type == "progressive":
701:                 if loss_name == "topology":
702:                     start_weight = self.config.topology_start_weight
703:                     end_weight = self.config.topology_end_weight
704:                     ramp_epochs = self.config.topology_ramp_epochs
705:                     progress = min(current_epoch / ramp_epochs, 1.0)
706:                     scheduled_weights[loss_name] = start_weight + progress * (end_weight -
+                         start_weight)
707:
708:             elif schedule_type == "linear_ramp":
709:                 progress = stage_epoch / max(total_stage_epochs, 1)
710:                 scheduled_weights[loss_name] = base_weight * progress
711:
712:             elif schedule_type == "exponential":
713:                 progress = stage_epoch / max(total_stage_epochs, 1)
714:                 scheduled_weights[loss_name] = base_weight * (progress ** 2)
715:
716:             elif schedule_type == "early_decay":
717:                 if current_stage > 1:
718:                     scheduled_weights[loss_name] = base_weight * 0.3
719:
720:             elif schedule_type == "staged_ramp":
721:                 if current_stage == 2:
722:                     progress = stage_epoch / max(total_stage_epochs, 1)
723:                     scheduled_weights[loss_name] = base_weight * progress
724:                 elif current_stage < 2:
725:                     scheduled_weights[loss_name] = 0.0
726:
727:             elif schedule_type == "late_ramp":
728:                 if current_stage == 3:
729:                     progress = stage_epoch / max(total_stage_epochs, 1)
730:                     scheduled_weights[loss_name] = base_weight * progress
731:                 elif current_stage < 3:
732:                     scheduled_weights[loss_name] = 0.0
733:
734:             elif schedule_type == "mid_ramp":

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```

735:         if current_stage >= 2:
736:             if current_stage == 2:
737:                 progress = min(stage_epoch / (total_stage_epochs * 0.5), 1.0)
738:                 scheduled_weights[loss_name] = base_weight * progress
739:             else:
740:                 scheduled_weights[loss_name] = base_weight
741:         else:
742:             scheduled_weights[loss_name] = 0.0
743:
744:     elif schedule_type == "delayed_ramp":
745:         if current_epoch >= self.config.graph_start_epoch:
746:             epochs_since_start = current_epoch - self.config.graph_start_epoch
747:             ramp_duration = 50
748:             progress = min(epochs_since_start / ramp_duration, 1.0)
749:             scheduled_weights[loss_name] = self.config.graph_end_weight * progress
750:         else:
751:             scheduled_weights[loss_name] = 0.0
752:
753:     return scheduled_weights

```

File: training\trainer.py

```

=====
1: """
2: Dynamic Multi-stage training system with adaptive curriculum learning
3: Implements novel training strategies: dynamic stage transitions, topology-aware scheduling,
4: multi-objective optimization, and cross-modal consistency learning
5: """
6:
7: import torch
8: import torch.nn.utils
9:
10: # training/trainer.py - Fixed AMP imports
11: from torch.amp import autocast, GradScaler
12: import time
13: import numpy as np
14: import random
15: from pathlib import Path
16: from tqdm import tqdm
17: from typing import Dict, List, Optional, Tuple
18: from collections import deque
19:
20: from .losses import ResearchGradeLoss, LossScheduler
21: from config import DEFAULT_TRAINING_CONFIG, DEFAULT_LOSS_CONFIG, StageTransitionCriteria
22:
23:
24: class CurriculumState:
25:     """Tracks curriculum learning state and metrics"""
26:
27:     def __init__(self, config):
28:         self.config = config
29:
30:         # Loss history for plateau detection
31:         self.loss_history = {
32:             "stage1": deque(maxlen=config.plateau_detection_window * 2),
33:             "stage2": deque(maxlen=config.plateau_detection_window * 2),
34:             "stage3": deque(maxlen=config.plateau_detection_window * 2),
35:         }
36:
37:         # Component loss tracking
38:         self.component_losses = {
39:             "segmentation": deque(maxlen=20),
40:             "dice": deque(maxlen=20),
41:             "polygon": deque(maxlen=20),
42:             "voxel": deque(maxlen=20),
43:             "topology": deque(maxlen=20),
44:             "latent_consistency": deque(maxlen=20),
45:             "graph": deque(maxlen=20),
46:         }
47:
48:         # Gradient magnitude tracking for dynamic weighting
49:         self.gradient_norms = {

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50:         name: deque(maxlen=config.gradient_norm_window)
51:         for name in self.component_losses.keys():
52:     }
53:
54:     # Stage transition tracking
55:     self.epochs_without_improvement = 0
56:     self.best_val_loss = float("inf")
57:     self.stage_transition_epochs = []
58:
59:     # Dynamic weights history
60:     self.weight_history = []
61:
62:     def update_loss_history(self, stage: str, val_loss: float):
63:         """Update validation loss history for plateau detection"""
64:         if stage in self.loss_history:
65:             self.loss_history[stage].append(val_loss)
66:
67:         # Update improvement tracking
68:         if val_loss < self.best_val_loss:
69:             self.best_val_loss = val_loss
70:             self.epochs_without_improvement = 0
71:         else:
72:             self.epochs_without_improvement += 1
73:
74:     def update_component_losses(self, loss_components: Dict[str, float]):
75:         """Update individual loss component history"""
76:         for name, loss_val in loss_components.items():
77:             if name in self.component_losses:
78:                 self.component_losses[name].append(loss_val)
79:
80:     def should_transition(self, current_stage: int) -> bool:
81:         """Check if should transition to next stage"""
82:         if current_stage == 1:
83:             val_losses = list(self.loss_history["stage1"])
84:             return StageTransitionCriteria.should_transition_from_stage1(
85:                 [], val_losses, self.config
86:             )
87:         elif current_stage == 2:
88:             polygon_losses = list(self.component_losses["polygon"])
89:             return StageTransitionCriteria.should_transition_from_stage2(
90:                 polygon_losses, self.config
91:             )
92:
93:         return False
94:
95:
96: class AdaptiveMultiStageTrainer:
97:     """
98:     Advanced multi-stage trainer with dynamic curriculum learning:
99:     - Adaptive stage transitioning based on performance plateaus
100:    - Topology-aware loss scheduling
101:    - Multi-objective optimization with dynamic weighting
102:    - Cross-modal latent consistency learning
103:    - Graph-based topology constraints
104:    """
105:
106:    # Class constant for rolling checkpoint path
107:    ROLLING_CHECKPOINT = "latest_checkpoint.pth"
108:
109:    def __init__(self, model, train_loader, val_loader, device=None, config=None):
110:        if config is None:
111:            config = DEFAULT_TRAINING_CONFIG
112:
113:        self.model = model.to(device or config.device)
114:        self.train_loader = train_loader
115:        self.val_loader = val_loader
116:        self.device = device or config.device
117:        self.config = config
118:
119:        # Initialize curriculum state
120:        self.curriculum_state = CurriculumState(config.curriculum)
121:        self.loss_scheduler = LossScheduler(config.curriculum)
122:

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123:         # Training state tracking for resume functionality
124:         self.current_stage = 1
125:         self.current_epoch = 0
126:         self.global_epoch = 0
127:         self.stage_epoch = 0
128:         self.stage_start_time = None
129:         self.epoch_times = []
130:
131:         # Add AMP and optimization settings - Updated for new PyTorch API
132:         self.use_amp = getattr(config, "use_mixed_precision", True)
133:         self.scaler = GradScaler("cuda", enabled=self.use_amp)
134:         self.accumulation_steps = getattr(config, "accumulation_steps", 1)
135:         self.dvx_step_freq = getattr(config, "dvx_step_freq", 1)
136:         self.voxel_size_stage = getattr(config, "voxel_size_stage", None)
137:         self.image_size_stage = getattr(config, "image_size_stage", None)
138:         self._step = 0
139:
140:         # Enhanced optimizers with better hyperparameters
141:         self.optimizer_2d = torch.optim.AdamW(
142:             list(self.model.encoder.parameters())
143:             + list(self.model.seg_head.parameters())
144:             + list(self.model.attr_head.parameters())
145:             + list(self.model.sdf_head.parameters()),
146:             lr=config.stage1_lr,
147:             weight_decay=config.stage1_weight_decay,
148:             betas=(0.9, 0.999),
149:         )
150:
151:         self.optimizer_dvx = torch.optim.AdamW(
152:             self.model.dvx.parameters(),
153:             lr=config.stage2_lr,
154:             weight_decay=config.stage2_weight_decay,
155:             betas=(0.9, 0.999),
156:         )
157:
158:         self.optimizer_full = torch.optim.AdamW(
159:             self.model.parameters(),
160:             lr=config.stage3_lr,
161:             weight_decay=config.stage3_weight_decay,
162:             betas=(0.9, 0.999),
163:         )
164:
165:         # Enhanced learning rate schedulers with proper minimum LR
166:         if config.use_cosine_restarts:
167:             self.scheduler_2d = torch.optim.lr_scheduler.CosineAnnealingWarmRestarts(
168:                 self.optimizer_2d, T_0=20, T_mult=1,
169:                 eta_min=config.stage1_lr * 0.1 # Min LR is 10% of initial
170:             )
171:             self.scheduler_dvx = torch.optim.lr_scheduler.CosineAnnealingWarmRestarts(
172:                 self.optimizer_dvx, T_0=15, T_mult=1,
173:                 eta_min=config.stage2_lr * 0.1
174:             )
175:             self.scheduler_full = torch.optim.lr_scheduler.CosineAnnealingWarmRestarts(
176:                 self.optimizer_full, T_0=30, T_mult=1,
177:                 eta_min=config.stage3_lr * 0.1
178:             )
179:         else:
180:             self.scheduler_2d = torch.optim.lr_scheduler.CosineAnnealingLR(
181:                 self.optimizer_2d, T_max=config.max_stage1_epochs,
182:                 eta_min=config.stage1_lr * 0.1 # Min LR is 10% of initial
183:             )
184:             self.scheduler_dvx = torch.optim.lr_scheduler.CosineAnnealingLR(
185:                 self.optimizer_dvx, T_max=config.max_stage2_epochs,
186:                 eta_min=config.stage2_lr * 0.1
187:             )
188:             self.scheduler_full = torch.optim.lr_scheduler.CosineAnnealingLR(
189:                 self.optimizer_full, T_max=config.max_stage3_epochs,
190:                 eta_min=config.stage3_lr * 0.1
191:             )
192:
193:         # Enhanced loss function with dynamic weighting
194:         base_loss_kwargs = {
195:             k: v

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196:         for k, v in DEFAULT_LOSS_CONFIG.__dict__.items()
197:             if k != "enable_dynamic_weighting"
198:     }
199:     self.loss_fn = ResearchGradeLoss(
200:         **base_loss_kwargs,
201:         enable_dynamic_weighting=bool(config.curriculum.use_gradnorm),
202:         gradnorm_alpha=float(config.curriculum.gradnorm_alpha),
203:         device=self.device,
204:     )
205:
206:     self.history = {
207:         "stage1": {"train_loss": [], "val_loss": [], "component_losses": []},
208:         "stage2": {"train_loss": [], "val_loss": [], "component_losses": []},
209:         "stage3": {"train_loss": [], "val_loss": [], "component_losses": []},
210:         "stage_transitions": [],
211:         "dynamic_weights": [],
212:         "curriculum_events": [],
213:     }
214:
215:     def _get_eta_string(self, epoch, total_epochs):
216:         """Calculate and format ETA string"""
217:         if len(self.epoch_times) == 0:
218:             return "ETA: calculating..."
219:
220:         avg_epoch_time = sum(self.epoch_times) / len(self.epoch_times)
221:         remaining_epochs = total_epochs - epoch - 1
222:         eta_seconds = avg_epoch_time * remaining_epochs
223:
224:         if eta_seconds < 60:
225:             return f"ETA: {int(eta_seconds)}s"
226:         elif eta_seconds < 3600:
227:             return f"ETA: {int(eta_seconds // 60)}m {int(eta_seconds % 60)}s"
228:         else:
229:             hours = int(eta_seconds // 3600)
230:             minutes = int((eta_seconds % 3600) // 60)
231:             return f"ETA: {hours}h {minutes}m"
232:
233:     def _get_shared_parameters(self):
234:         """Get shared parameters for GradNorm weighting"""
235:         # Return encoder parameters as shared across tasks
236:         return list(self.model.encoder.parameters())
237:
238:     def _update_loss_weights_for_curriculum(
239:         self, current_stage: int, stage_epoch: int, total_stage_epochs: int
240:     ):
241:         """Update loss weights based on curriculum schedule"""
242:         base_weights = {
243:             "seg": self.loss_fn.initial_weights["seg"],
244:             "dice": self.loss_fn.initial_weights["dice"],
245:             "sdf": self.loss_fn.initial_weights["sdf"],
246:             "attr": self.loss_fn.initial_weights["attr"],
247:             "polygon": self.loss_fn.initial_weights["polygon"],
248:             "voxel": self.loss_fn.initial_weights["voxel"],
249:             "topology": self.loss_fn.initial_weights["topology"],
250:             "latent_consistency": self.loss_fn.initial_weights["latent_consistency"],
251:             "graph": self.loss_fn.initial_weights["graph"],
252:         }
253:
254:         scheduled_weights = self.loss_scheduler.get_scheduled_weights(
255:             current_stage,
256:             self.global_epoch,
257:             stage_epoch,
258:             total_stage_epochs,
259:             base_weights,
260:         )
261:
262:         self.loss_fn.update_loss_weights(scheduled_weights)
263:
264:         # Log weight changes
265:         self.history["dynamic_weights"].append(
266:             {
267:                 "epoch": self.global_epoch,
268:                 "stage": current_stage,

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269:         "weights": scheduled_weights.copy(),
270:     }
271: )
272:
273: def _train_epoch(self, mode="stage1"):
274:     """Enhanced training epoch with improved stability and speed"""
275:     self.model.train()
276:     total_loss = 0
277:     component_loss_sums = {}
278:
279:     # Select optimizer and apply gradient scaling
280:     if mode == "stage1":
281:         optimizer = self.optimizer_2d
282:     elif mode == "stage2":
283:         optimizer = self.optimizer_dvx
284:     else:
285:         optimizer = self.optimizer_full
286:
287:     # Improved progress tracking
288:     train_pbar = tqdm(
289:         self.train_loader, desc=f"Training {mode.upper()}", leave=False, ncols=120
290:     )
291:
292:     batch_count = 0
293:     epoch_start_time = time.time()
294:
295:     # Add gradient accumulation tracking
296:     accumulated_loss = 0.0
297:
298:     for batch_idx, batch in enumerate(train_pbar):
299:         self._step += 1
300:         batch = {
301:             k: v.to(self.device, non_blocking=True) if torch.is_tensor(v) else v
302:             for k, v in batch.items()
303:         }
304:
305:         # Smart geometric computation gating
306:         run_full_geometric = (
307:             mode == "stage3" or # Always run in final stage
308:             (mode == "stage2" and self._step % 1 == 0) or # Every other step in stage 2
309:             (mode == "stage1" and self._step % 2 == 0) # Every 4th step in stage 1
310:         )
311:
312:         with autocast("cuda", enabled=self.use_amp):
313:             predictions = self.model(
314:                 batch["image"], run_full_geometric=run_full_geometric
315:             )
316:
317:             targets = self._prepare_targets(batch, mode)
318:
319:             shared_params = (
320:                 self._get_shared_parameters()
321:                 if self.config.curriculum.use_gradnorm
322:                 else None
323:             )
324:
325:             loss, loss_components = self.loss_fn(
326:                 predictions,
327:                 targets,
328:                 shared_params,
329:                 run_full_geometric=run_full_geometric,
330:             )
331:
332:             # Scale for accumulation
333:             loss = loss / self.accumulation_steps
334:             accumulated_loss += loss.item()
335:
336:             # Backward pass with stability
337:             self.scaler.scale(loss).backward()
338:
339:             # Gradient accumulation and update
340:             if ((batch_idx + 1) % self.accumulation_steps) == 0:
341:                 # Enhanced gradient clipping

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```

342:         self.scaler.unscale_(optimizer)
343:
344:         # Adaptive gradient clipping based on loss magnitude
345:         max_grad_norm = min(self.config.grad_clip_norm * (1.0 + accumulated_loss), 2.0)
346:         torch.nn.utils.clip_grad_norm_(
347:             self.model.parameters(), max_grad_norm
348:         )
349:
350:         self.scaler.step(optimizer)
351:         self.scaler.update()
352:         optimizer.zero_grad()
353:
354:         # Reset accumulation
355:         accumulated_loss = 0.0
356:
357:         current_loss = loss.item() * self.accumulation_steps
358:         total_loss += current_loss
359:
360:         # Track components with better averaging
361:         for name, component_loss in loss_components.items():
362:             if name != "total":
363:                 loss_val = (
364:                     component_loss.item()
365:                     if torch.is_tensor(component_loss)
366:                     else component_loss
367:                 )
368:                 if name not in component_loss_sums:
369:                     component_loss_sums[name] = []
370:                 component_loss_sums[name].append(loss_val)
371:
372:         batch_count += 1
373:
374:         # Less frequent but more informative logging
375:         if (batch_idx + 1) % 100 == 0:
376:             elapsed = time.time() - epoch_start_time
377:             avg_time_per_batch = elapsed / (batch_idx + 1)
378:
379:             # Show meaningful component averages
380:             recent_components = {}
381:             for name, vals in component_loss_sums.items():
382:                 if len(vals) >= 10: # Only show if we have enough samples
383:                     recent_avg = np.mean(vals[-10:]) # Last 10 batches
384:                     if recent_avg > 0.01: # Only show significant components
385:                         recent_components[name] = recent_avg
386:
387:             comp_str = ", ".join([f"{k}:{v:.3f}" for k, v in recent_components.items()])
388:             print(f"[Epoch {self.global_epoch}] Batch {batch_idx+1} | "
389:                   f"{avg_time_per_batch:.2f}s/batch | loss:{total_loss/batch_count:.4f} | "
390:                   f"{comp_str}")
391:
392:             # Update progress with meaningful info
393:             train_pbar.set_postfix({
394:                 "loss": f"{current_loss:.4f}",
395:                 "lr": f"{optimizer.param_groups[0]['lr']:.6f}"
396:             })
397:
398:             # Calculate proper component averages
399:             avg_component_losses = {}
400:             for name, loss_list in component_loss_sums.items():
401:                 if loss_list:
402:                     avg_component_losses[name] = np.mean(loss_list)
403:                 else:
404:                     avg_component_losses[name] = 0.0
405:
406:             return total_loss / batch_count, avg_component_losses
407:
408:     def _prepare_targets(self, batch, mode):
409:         """Prepare targets based on training mode"""
410:         if mode == "stage1":
411:             return {"mask": batch["mask"], "attributes": batch["attributes"]}
412:         elif mode == "stage2":
413:             return {
414:                 "polygons_gt": {

```



```

414:         "polygons": batch["polygons_gt"]["polygons"].to(self.device),
415:         "valid_mask": batch["polygons_gt"]["valid_mask"].to(self.device),
416:     }
417: }
418: else: # stage3
419:     return {
420:         "mask": batch["mask"],
421:         "attributes": batch["attributes"],
422:         "voxels_gt": batch["voxels_gt"],
423:         "polygons_gt": {
424:             "polygons": batch["polygons_gt"]["polygons"].to(self.device),
425:             "valid_mask": batch["polygons_gt"]["valid_mask"].to(self.device),
426:         },
427:     }
428:
429: def _validate(self, mode="stage1"):
430:     """Enhanced validation with consistent loss computation"""
431:     self.model.eval()
432:     total_loss = 0
433:     component_loss_sums = {}
434:
435:     val_pbar = tqdm(
436:         self.val_loader, desc=f"Validating {mode.upper()}", leave=False, ncols=120
437:     )
438:
439:     batch_count = 0
440:     with torch.no_grad():
441:         for batch in val_pbar:
442:             batch = {
443:                 k: v.to(self.device, non_blocking=True) if torch.is_tensor(v) else v
444:                 for k, v in batch.items()
445:             }
446:
447:             with autocast("cuda", enabled=self.use_amp):
448:                 # ALWAYS run full geometric in validation for consistency
449:                 predictions = self.model(batch["image"], run_full_geometric=True)
450:
451:                 targets = self._prepare_targets(batch, "stage3") # Use full targets
452:
453:                 # Use same loss computation as training but without dynamic weighting
454:                 loss, loss_components = self.loss_fn(
455:                     predictions, targets, shared_parameters=None, run_full_geometric=True
456:                 )
457:
458:                 current_loss = loss.item()
459:                 total_loss += current_loss
460:
461:                 # Track component losses properly
462:                 for name, component_loss in loss_components.items():
463:                     if name != "total":
464:                         loss_val = (
465:                             component_loss.item()
466:                             if torch.is_tensor(component_loss)
467:                             else component_loss
468:                         )
469:                         if name not in component_loss_sums:
470:                             component_loss_sums[name] = []
471:                         component_loss_sums[name].append(loss_val)
472:
473:                 batch_count += 1
474:                 val_pbar.set_postfix({"loss": f"{current_loss:.4f}"})
475:
476:     # Calculate proper averages
477:     avg_component_losses = {}
478:     for name, loss_list in component_loss_sums.items():
479:         if loss_list:
480:             avg_component_losses[name] = np.mean(loss_list)
481:         else:
482:             avg_component_losses[name] = 0.0
483:
484:     return total_loss / batch_count, avg_component_losses
485:
486: def train_stage_adaptive(self, stage: int, max_epochs: int, min_epochs: int):

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487:     """
488:     Train a stage with adaptive termination based on curriculum learning
489:
490:     Args:
491:         stage: Stage number (1, 2, 3)
492:         max_epochs: Maximum epochs for this stage
493:         min_epochs: Minimum epochs before considering transition
494:     """
495:     print("=" * 60)
496:     print(f"STAGE {stage}: Adaptive Training with Dynamic Curriculum")
497:     print("=" * 60)
498:
499:     self.current_stage = stage
500:     self.stage_start_time = time.time()
501:
502:     # Only reset if not resuming
503:     if not hasattr(self, "epoch_times") or self.epoch_times is None:
504:         self.epoch_times = []
505:
506:     start_epoch = int(self.stage_epoch or 0)
507:
508:     # Set parameter gradients for current stage
509:     self._configure_stage_parameters(stage)
510:
511:     mode_name = f"stage{stage}"
512:
513:     for epoch in range(start_epoch, max_epochs):
514:         epoch_start_time = time.time()
515:         self.stage_epoch = epoch
516:         self.global_epoch += 1
517:
518:         # Update loss weights based on curriculum
519:         self._update_loss_weights_for_curriculum(stage, epoch, max_epochs)
520:
521:         print(
522:             f"\nStage {stage} - Epoch {epoch+1}/{max_epochs} (Global: {self.global_epoch})"
523:         )
524:
525:         # Training and validation
526:         train_loss, train_components = self._train_epoch(mode_name)
527:         val_loss, val_components = self._validate(mode_name)
528:
529:         # Record epoch time
530:         epoch_time = time.time() - epoch_start_time
531:         self.epoch_times.append(epoch_time)
532:
533:         if len(self.epoch_times) > 10:
534:             self.epoch_times.pop(0)
535:
536:         # Update curriculum state
537:         self.curriculum_state.update_loss_history(mode_name, val_loss)
538:         self.curriculum_state.update_component_losses(val_components)
539:
540:         # Store training history
541:         self.history[mode_name]["train_loss"].append(train_loss)
542:         self.history[mode_name]["val_loss"].append(val_loss)
543:         self.history[mode_name]["component_losses"].append(val_components)
544:
545:         # Update learning rate
546:         if stage == 1:
547:             self.scheduler_2d.step()
548:             current_lr = self.optimizer_2d.param_groups[0]['lr']
549:         elif stage == 2:
550:             self.scheduler_dvx.step()
551:             current_lr = self.optimizer_dvx.param_groups[0]['lr']
552:         else:
553:             self.scheduler_full.step()
554:             current_lr = self.optimizer_full.param_groups[0]['lr']
555:
556:         # Log learning rate every 10 epochs
557:         if (epoch + 1) % 10 == 0:
558:             print(f"Learning rate at epoch {epoch + 1}: {current_lr:.6f}")
559:

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560:         # Display comprehensive results
561:         self._display_epoch_results(
562:             epoch,
563:             max_epochs,
564:             train_loss,
565:             val_loss,
566:             train_components,
567:             val_components,
568:             epoch_time,
569:         )
570:
571:         # Check for adaptive stage transition
572:         if epoch >= min_epochs:
573:             should_transition = self.curriculum_state.should_transition(stage)
574:             if should_transition:
575:                 print(
576:                     f"\n? ADAPTIVE TRANSITION: Stage {stage} converged after {epoch+1} epochs"
577:                 )
578:                 print(
579:                     "    Detected performance plateau - transitioning to next stage"
580:                 )
581:
582:                 self.history["stage_transitions"].append(
583:                     {
584:                         "from_stage": stage,
585:                         "epoch": epoch + 1,
586:                         "global_epoch": self.global_epoch,
587:                         "reason": "performance_plateau",
588:                     }
589:                 )
590:
591:                 self.history["curriculum_events"].append(
592:                     {
593:                         "type": "stage_transition",
594:                         "stage": stage,
595:                         "epoch": self.global_epoch,
596:                         "details": f"Converged after {epoch+1} epochs",
597:                     }
598:                 )
599:                 break
600:
601:         # Save rolling checkpoint
602:         if (epoch + 1) % self.config.checkpoint_freq == 0:
603:             self._save_rolling_checkpoint()
604:
605:         print(f"\nStage {stage} completed after {epoch+1} epochs")
606:
607:     def _configure_stage_parameters(self, stage: int):
608:         """Configure which parameters require gradients for each stage"""
609:         # First freeze everything
610:         for param in self.model.parameters():
611:             param.requires_grad = False
612:
613:         if stage == 1:
614:             # Stage 1: Segmentation + Attributes (2D only)
615:             for param in self.model.encoder.parameters():
616:                 param.requires_grad = True
617:             for param in self.model.seg_head.parameters():
618:                 param.requires_grad = True
619:             for param in self.model.attr_head.parameters():
620:                 param.requires_grad = True
621:             for param in self.model.sdf_head.parameters():
622:                 param.requires_grad = True
623:
624:         elif stage == 2:
625:             # Stage 2: DVX training (polygon fitting) - keep encoder frozen initially
626:             for param in self.model.dvx.parameters():
627:                 param.requires_grad = True
628:             # Optionally unfreeze encoder in later epochs
629:             if self.stage_epoch > 10:
630:                 for param in self.model.encoder.parameters():
631:                     param.requires_grad = True
632:

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633:         else: # stage == 3
634:             # Stage 3: End-to-end fine-tuning (all parameters)
635:             for param in self.model.parameters():
636:                 param.requires_grad = True
637:
638:     def _display_epoch_results(
639:         self,
640:         epoch: int,
641:         total_epochs: int,
642:         train_loss: float,
643:         val_loss: float,
644:         train_components: Dict,
645:         val_components: Dict,
646:         epoch_time: float,
647:     ):
648:         """Display comprehensive epoch results with curriculum information"""
649:         eta_str = self._get_eta_string(epoch, total_epochs)
650:
651:         print(f"Train Loss: {train_loss:.4f}, Val Loss: {val_loss:.4f}")
652:         print(f"Epoch time: {epoch_time:.1f}s, {eta_str}")
653:
654:         # Show significant component losses
655:         significant_components = {
656:             k: v
657:             for k, v in val_components.items()
658:             if v > 0.01
659:             and k
660:             in [
661:                 "seg",
662:                 "dice",
663:                 "polygon",
664:                 "voxel",
665:                 "topology",
666:                 "latent_consistency",
667:                 "graph",
668:             ]
669:         }
670:         if significant_components:
671:             comp_str = ", ".join(
672:                 [f"{k}: {v:.3f}" for k, v in significant_components.items()]
673:             )
674:             print(f"Components: {comp_str}")
675:
676:         # Show current loss weights for active components
677:         active_weights = {k: v for k, v in self.loss_fn.weights.items() if v > 0.001}
678:         if active_weights:
679:             weight_str = ", ".join([f"{k}: {v:.3f}" for k, v in active_weights.items()])
680:             print(f"Weights: {weight_str}")
681:
682:         # Show curriculum status
683:         plateau_epochs = self.curriculum_state.epochs_without_improvement
684:         if plateau_epochs > 0:
685:             print(f"Plateau: {plateau_epochs} epochs without improvement")
686:
687:     def _save_rolling_checkpoint(self):
688:         """Enhanced checkpoint saving with curriculum state, RNG state, and scaler state"""
689:         checkpoint = {
690:             "model_state_dict": self.model.state_dict(),
691:             "optimizer_2d_state_dict": self.optimizer_2d.state_dict(),
692:             "optimizer_dvx_state_dict": self.optimizer_dvx.state_dict(),
693:             "optimizer_full_state_dict": self.optimizer_full.state_dict(),
694:             "scheduler_2d_state_dict": self.scheduler_2d.state_dict(),
695:             "scheduler_dvx_state_dict": self.scheduler_dvx.state_dict(),
696:             "scheduler_full_state_dict": self.scheduler_full.state_dict(),
697:             "scaler_state_dict": self.scaler.state_dict(), # Add AMP scaler state
698:             "loss_fn_state": {
699:                 "weights": self.loss_fn.weights,
700:                 "initial_weights": self.loss_fn.initial_weights,
701:             },
702:             "history": self.history,
703:             "config": self.config,
704:             "current_stage": self.current_stage,
705:             "current_epoch": self.current_epoch,

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706:         "global_epoch": self.global_epoch,
707:         "stage_epoch": self.stage_epoch,
708:         "epoch_times": self.epoch_times,
709:         "step_counter": self._step, # Save step counter for DVX gating
710:         "curriculum_state": {
711:             "loss_history": dict(self.curriculum_state.loss_history),
712:             "component_losses": dict(self.curriculum_state.component_losses),
713:             "epochs_without_improvement": self.curriculum_state.epochs_without_improvement,
714:             "best_val_loss": self.curriculum_state.best_val_loss,
715:             "stage_transition_epochs": self.curriculum_state.stage_transition_epochs,
716:         },
717:         "rng_state": {
718:             "torch": torch.get_rng_state(),
719:             "cuda": torch.cuda.get_rng_state_all()
720:             if torch.cuda.is_available()
721:             else None,
722:             "numpy": np.random.get_state(),
723:             "python": random.getstate(),
724:         },
725:     }
726:
727:     checkpoint_path = self.ROLLING_CHECKPOINT
728:     torch.save(checkpoint, checkpoint_path)
729:     print(f"Rolling checkpoint saved: {checkpoint_path}")
730:
731:     def load_checkpoint(self, filename):
732:         """
733:         Enhanced checkpoint loading with architecture compatibility handling
734:         Safely handles model architecture changes by filtering incompatible parameters
735:         """
736:         print(f>Loading checkpoint: {filename}")
737:         checkpoint = torch.load(filename, map_location=self.device, weights_only=False)
738:
739:         # === SAFE MODEL STATE LOADING ===
740:         model_state = checkpoint["model_state_dict"]
741:         current_model_keys = set(self.model.state_dict().keys())
742:
743:         # Filter parameters into compatible and incompatible
744:         compatible_state = {}
745:         incompatible_keys = []
746:         missing_keys = []
747:
748:         # Check each parameter in the checkpoint
749:         for key, value in model_state.items():
750:             if key in current_model_keys:
751:                 # Check if tensor shapes match
752:                 current_param = self.model.state_dict()[key]
753:                 if current_param.shape == value.shape:
754:                     compatible_state[key] = value
755:                 else:
756:                     incompatible_keys.append(f"{key} (shape mismatch: {value.shape} ->
+                     {current_param.shape})")
757:             else:
758:                 incompatible_keys.append(f"{key} (parameter not found in current model)")
759:
760:         # Check for missing parameters in checkpoint
761:         for key in current_model_keys:
762:             if key not in model_state:
763:                 missing_keys.append(key)
764:
765:         # Load compatible parameters only
766:         loaded_keys, unexpected_keys = self.model.load_state_dict(compatible_state, strict=False)
767:
768:         # Report parameter loading status
769:         print(f"? Successfully loaded {len(compatible_state)} compatible parameters")
770:
771:         if incompatible_keys:
772:             print(f"? Skipped {len(incompatible_keys)} incompatible parameters:")
773:             for key in incompatible_keys[:10]: # Show first 10
774:                 print(f"    - {key}")
775:             if len(incompatible_keys) > 10:
776:                 print(f"    ... and {len(incompatible_keys) - 10} more")
777:

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778:         if missing_keys:
779:             print(f"? {len(missing_keys)} parameters will use random initialization:")
780:             for key in missing_keys[:10]: # Show first 10
781:                 print(f"    - {key}")
782:             if len(missing_keys) > 10:
783:                 print(f"    ... and {len(missing_keys) - 10} more")
784:
785:         # === OPTIMIZER STATES LOADING ===
786:         try:
787:             self.optimizer_2d.load_state_dict(checkpoint["optimizer_2d_state_dict"])
788:             print("? Loaded optimizer_2d state")
789:         except Exception as e:
790:             print(f"? Could not load optimizer_2d state: {e}")
791:
792:         try:
793:             self.optimizer_dvx.load_state_dict(checkpoint["optimizer_dvx_state_dict"])
794:             print("? Loaded optimizer_dvx state")
795:         except Exception as e:
796:             print(f"? Could not load optimizer_dvx state: {e}")
797:
798:         try:
799:             self.optimizer_full.load_state_dict(checkpoint["optimizer_full_state_dict"])
800:             print("? Loaded optimizer_full state")
801:         except Exception as e:
802:             print(f"? Could not load optimizer_full state: {e}")
803:
804:         # === AMP SCALER STATE ===
805:         if "scaler_state_dict" in checkpoint:
806:             try:
807:                 self.scaler.load_state_dict(checkpoint["scaler_state_dict"])
808:                 print("? Loaded AMP scaler state")
809:             except Exception as e:
810:                 print(f"? Could not load scaler state: {e}")
811:
812:         # === SCHEDULER STATES ===
813:         scheduler_mappings = [
814:             ("scheduler_2d_state_dict", self.scheduler_2d),
815:             ("scheduler_dvx_state_dict", self.scheduler_dvx),
816:             ("scheduler_full_state_dict", self.scheduler_full),
817:         ]
818:
819:         for state_key, scheduler_obj in scheduler_mappings:
820:             if state_key in checkpoint:
821:                 try:
822:                     scheduler_obj.load_state_dict(checkpoint[state_key])
823:                     print(f"? Loaded {state_key.replace('_state_dict', '')} scheduler")
824:                 except Exception as e:
825:                     print(f"? Could not load {state_key}: {e}")
826:
827:         # === LOSS FUNCTION STATE ===
828:         if "loss_fn_state" in checkpoint:
829:             try:
830:                 loaded_weights = checkpoint["loss_fn_state"]["weights"]
831:                 if isinstance(loaded_weights, dict):
832:                     # Handle device transfer for tensor weights
833:                     self.loss_fn.weights = {
834:                         k: (v.to(self.device) if torch.is_tensor(v) else v)
835:                         for k, v in loaded_weights.items()
836:                     }
837:                 else:
838:                     self.loss_fn.weights = loaded_weights
839:
840:                 self.loss_fn.initial_weights = checkpoint["loss_fn_state"]["initial_weights"]
841:                 print("? Loaded loss function weights")
842:             except Exception as e:
843:                 print(f"? Could not load loss function state: {e}")
844:
845:         # === TRAINING HISTORY ===
846:         if "history" in checkpoint:
847:             self.history = checkpoint["history"]
848:             print("? Loaded training history")
849:
850:         # === TRAINING STATE VARIABLES ===

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851:     state_variables = [
852:         ("current_stage", "current_stage"),
853:         ("current_epoch", "current_epoch"),
854:         ("global_epoch", "global_epoch"),
855:         ("stage_epoch", "stage_epoch"),
856:         ("epoch_times", "epoch_times"),
857:         ("step_counter", "_step"),
858:     ]
859:
860:     for checkpoint_key, attr_name in state_variables:
861:         if checkpoint_key in checkpoint:
862:             setattr(self, attr_name, checkpoint[checkpoint_key])
863:             print(f"? Restored {checkpoint_key}: {getattr(self, attr_name)}")
864:
865:     # === CURRICULUM STATE RESTORATION ===
866:     if "curriculum_state" in checkpoint:
867:         try:
868:             cs = checkpoint["curriculum_state"]
869:
870:             # Restore loss history deque
871:             for key, history in cs.get("loss_history", {}).items():
872:                 self.curriculum_state.loss_history[key] = deque(
873:                     history, maxlen=self.config.curriculum.plateau_detection_window * 2
874:                 )
875:
876:             # Restore component loss deque
877:             for key, history in cs.get("component_losses", {}).items():
878:                 self.curriculum_state.component_losses[key] = deque(history, maxlen=20)
879:
880:             # Restore curriculum metrics
881:             self.curriculum_state.epochs_without_improvement =
+                 cs.get("epochs_without_improvement", 0)
882:             self.curriculum_state.best_val_loss = cs.get("best_val_loss", float("inf"))
883:             self.curriculum_state.stage_transition_epochs = cs.get("stage_transition_epochs",
+                 [])
884:
885:             print(f"? Restored curriculum learning state")
886:         except Exception as e:
887:             print(f"? Could not restore curriculum state: {e}")
888:
889:     # === RNG STATE RESTORATION ===
890:     if "rng_state" in checkpoint:
891:         try:
892:             rs = checkpoint["rng_state"]
893:
894:             # Torch RNG (CPU)
895:             if "torch" in rs and rs["torch"] is not None:
896:                 torch_state = rs["torch"]
897:                 if torch.is_tensor(torch_state) and torch_state.dtype == torch.uint8:
898:                     torch.set_rng_state(torch_state)
899:                 else:
900:                     torch.set_rng_state(torch.tensor(torch_state, dtype=torch.uint8))
901:
902:             # CUDA RNG (all devices)
903:             if "cuda" in rs and rs["cuda"] is not None and torch.cuda.is_available():
904:                 cuda_state = rs["cuda"]
905:                 cuda_tensors = []
906:                 for s in cuda_state:
907:                     if torch.is_tensor(s) and s.dtype == torch.uint8:
908:                         cuda_tensors.append(s)
909:                     else:
910:                         cuda_tensors.append(torch.tensor(s, dtype=torch.uint8))
911:                 torch.cuda.set_rng_state_all(cuda_tensors)
912:
913:             # NumPy RNG
914:             if "numpy" in rs and rs["numpy"] is not None:
915:                 np.random.set_state(rs["numpy"])
916:
917:             # Python random RNG
918:             if "python" in rs and rs["python"] is not None:
919:                 random.setstate(rs["python"])
920:
921:             print(f"? Restored RNG states for reproducibility")

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922:         except Exception as e:
923:             print(f"? Could not restore RNG states: {e}")
924:
925: # === DATALOADER STATE (if available) ===
926: if "dataloader_state" in checkpoint:
927:     try:
928:         dl_state = checkpoint["dataloader_state"]
929:         if (dl_state.get("train_sampler_state") is not None and
930:             hasattr(self.train_loader.sampler, "__dict__")):
931:             self.train_loader.sampler.__dict__.update(dl_state["train_sampler_state"])
932:
933:         if (dl_state.get("val_sampler_state") is not None and
934:             hasattr(self.val_loader.sampler, "__dict__")):
935:             self.val_loader.sampler.__dict__.update(dl_state["val_sampler_state"])
936:
937:         print("? Restored dataloader sampler states")
938:     except Exception as e:
939:         print(f"? Could not restore dataloader states: {e}")
940:
941: # === FINAL REPORT ===
942: print("\n" + "="*60)
943: print("CHECKPOINT LOADING SUMMARY")
944: print("="*60)
945: print(f"? Checkpoint loaded: {filename}")
946: print(f"? Resuming from Stage {self.current_stage}, Global Epoch {self.global_epoch}")
947: print(f"? Model parameters: {len(compatible_state)}/{len(model_state)} loaded successfully")
948:
949: if hasattr(self, 'curriculum_state'):
950:     print(f"? Curriculum state: {self.curriculum_state.epochs_without_improvement} epochs
+         without improvement")
951:
952: if incompatible_keys:
953:     print(f"? Architecture changes detected: {len(incompatible_keys)} parameters skipped")
954:     print(" This is normal after model architecture updates.")
955:
956: if missing_keys:
957:     print(f"? New parameters detected: {len(missing_keys)} will use random initialization")
958:     print(" These will be learned quickly during resumed training.")
959:
960: print("="*60)
961: print("Ready to resume adaptive multi-stage training!")
962: print("="*60)
963:
964: def train_all_stages(self):
965:     """
966:     Run complete adaptive multi-stage training pipeline
967:
968:     This is the main entry point that orchestrates the dynamic curriculum learning
969:     """
970:     if Path(self.ROLLING_CHECKPOINT).exists():
971:         print(f"Found existing checkpoint: {self.ROLLING_CHECKPOINT}")
972:         print("Resuming adaptive training from checkpoint...")
973:         self.load_checkpoint(self.ROLLING_CHECKPOINT)
974:     else:
975:         print("Starting fresh adaptive training pipeline...")
976:         self.current_stage = 1
977:         self.current_epoch = 0
978:         self.global_epoch = 0
979:
980:         print("\n" + "=" * 80)
981:         print("ADAPTIVE MULTI-STAGE TRAINING WITH DYNAMIC CURRICULUM")
982:         print("Novel Training Strategies:")
983:         print("? Adaptive Stage Transitioning (Dynamic Curriculum)")
984:         print("? Topology-aware Loss Scheduling")
985:         print("? Multi-objective Optimization with Dynamic Weighting")
986:         print("? Cross-modal Latent Consistency Learning")
987:         print("? Graph-based Topology Constraints")
988:         print("=" * 80)
989:
990:         # Stage 1: Adaptive 2D training
991:         if self.current_stage <= 1:
992:             print("\n? STAGE 1: Adaptive 2D Segmentation + Attributes Training")
993:             self.train_stage_adaptive(

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994:         stage=1,
995:         max_epochs=self.config.max_stage1_epochs,
996:         min_epochs=self.config.min_stage1_epochs,
997:     )
998:     self.current_stage = 2
999:     self.stage_epoch = 0
1000:     print("\nStage 1 completed. Transitioning to Stage 2...")
1001:
1002: # Stage 2: Adaptive DVX training
1003: if self.current_stage <= 2:
1004:     print("\n? STAGE 2: Adaptive DVX Polygon Fitting Training")
1005:     self.train_stage_adaptive(
1006:         stage=2,
1007:         max_epochs=self.config.max_stage2_epochs,
1008:         min_epochs=self.config.min_stage2_epochs,
1009:     )
1010:     self.current_stage = 3
1011:     self.stage_epoch = 0
1012:     print("\nStage 2 completed. Transitioning to Stage 3...")
1013:
1014: # Stage 3: Adaptive end-to-end fine-tuning
1015: if self.current_stage <= 3:
1016:     print("\n? STAGE 3: Adaptive End-to-End Fine-tuning with Full Loss Suite")
1017:     self.train_stage_adaptive(
1018:         stage=3,
1019:         max_epochs=self.config.max_stage3_epochs,
1020:         min_epochs=self.config.min_stage3_epochs,
1021:     )
1022:     print("\nStage 3 completed!")
1023:
1024: print("\n" + "=" * 80)
1025: print("? ALL ADAPTIVE TRAINING STAGES COMPLETED!")
1026: print("=" * 80)
1027:
1028: # Generate training report
1029: self._generate_training_report()
1030:
1031: # Save final model
1032: self._save_checkpoint("final_adaptive_model.pth")
1033:
1034: # Clean up rolling checkpoint
1035: if Path(self.ROLLING_CHECKPOINT).exists():
1036:     Path(self.ROLLING_CHECKPOINT).unlink()
1037:     print(f"Cleaned up rolling checkpoint: {self.ROLLING_CHECKPOINT}")
1038:
1039: return self.history
1040:
1041: def _generate_training_report(self):
1042:     """Generate comprehensive training report with curriculum insights"""
1043:     print("\n" + "=" * 60)
1044:     print("ADAPTIVE TRAINING REPORT")
1045:     print("=" * 60)
1046:
1047:     # Stage transition summary
1048:     if self.history["stage_transitions"]:
1049:         print("\n? Stage Transitions:")
1050:         for transition in self.history["stage_transitions"]:
1051:             print(
1052:                 f" ? Stage {transition['from_stage']} ? {transition['from_stage']+1}: "
1053:                 f"Epoch {transition['epoch']} (Global: {transition['global_epoch']})"
1054:             )
1055:             print(f" Reason: {transition['reason']}")
1056:
1057:     # Dynamic weight evolution
1058:     if self.history["dynamic_weights"]:
1059:         print(
1060:             f"\n?? Dynamic Weight Updates: {len(self.history['dynamic_weights'])} updates"
1061:         )
1062:         final_weights = self.history["dynamic_weights"][-1]["weights"]
1063:         print(" Final loss weights:")
1064:         for name, weight in final_weights.items():
1065:             if weight > 0.001:
1066:                 print(f" {name}: {weight:.3f}")

```

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1067:
1068:     # Curriculum events
1069:     if self.history["curriculum_events"]:
1070:         print(
1071:             f"\n? Curriculum Events: {len(self.history['curriculum_events'])} events"
1072:         )
1073:         for event in self.history["curriculum_events"][-5:]: # Show last 5 events
1074:             print(
1075:                 f"    ? {event['type']} at global epoch {event['epoch']}: {event['details']}"
1076:             )
1077:
1078:     # Performance summary
1079:     print("\n? Final Performance:")
1080:     for stage_name, data in self.history.items():
1081:         if isinstance(data, dict) and "val_loss" in data and data["val_loss"]:
1082:             final_loss = data["val_loss"][-1]
1083:             best_loss = min(data["val_loss"])
1084:             print(
1085:                 f"    ? {stage_name.upper()}: Final={final_loss:.4f}, Best={best_loss:.4f}"
1086:             )
1087:
1088:     print("\n? Training completed with novel adaptive curriculum strategies!")
1089:     print("=" * 60)
1090:
1091: def _save_checkpoint(self, filename):
1092:     """Save final training checkpoint"""
1093:     checkpoint = {
1094:         "model_state_dict": self.model.state_dict(),
1095:         "optimizer_2d_state_dict": self.optimizer_2d.state_dict(),
1096:         "optimizer_dvx_state_dict": self.optimizer_dvx.state_dict(),
1097:         "optimizer_full_state_dict": self.optimizer_full.state_dict(),
1098:         "scheduler_2d_state_dict": self.scheduler_2d.state_dict(),
1099:         "scheduler_dvx_state_dict": self.scheduler_dvx.state_dict(),
1100:         "scheduler_full_state_dict": self.scheduler_full.state_dict(),
1101:         "scaler_state_dict": self.scaler.state_dict(),
1102:         "loss_fn_state": {
1103:             "weights": self.loss_fn.weights,
1104:             "initial_weights": self.loss_fn.initial_weights,
1105:         },
1106:         "history": self.history,
1107:         "config": self.config,
1108:         "final_stage": self.current_stage,
1109:         "total_epochs": self.global_epoch,
1110:         "training_complete": True,
1111:         "curriculum_summary": {
1112:             "stage_transitions": len(self.history["stage_transitions"]),
1113:             "weight_updates": len(self.history["dynamic_weights"]),
1114:             "curriculum_events": len(self.history["curriculum_events"]),
1115:         },
1116:     }
1117:     torch.save(checkpoint, filename)
1118:     print(f"Final model saved: {filename}")
1119:
1120:
1121: # Legacy compatibility class
1122: class MultiStageTrainer(AdaptiveMultiStageTrainer):
1123:     """
1124:     Legacy wrapper for backward compatibility
1125:     Redirects to the new adaptive trainer
1126:     """
1127:
1128:     def __init__(self, *args, **kwargs):
1129:         super().__init__(*args, **kwargs)
1130:         print("Note: Using enhanced AdaptiveMultiStageTrainer with dynamic curriculum")
1131:
1132:     def train_stagel(self, epochs=None):
1133:         """Legacy method - redirects to adaptive training"""
1134:         max_epochs = epochs or self.config.max_stagel_epochs
1135:         min_epochs = self.config.min_stagel_epochs
1136:         return self.train_stage_adaptive(1, max_epochs, min_epochs)
1137:
1138:     def train_stage2(self, epochs=None):
1139:         """Legacy method - redirects to adaptive training"""

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1140:         max_epochs = epochs or self.config.max_stage2_epochs
1141:         min_epochs = self.config.min_stage2_epochs
1142:         return self.train_stage_adaptive(2, max_epochs, min_epochs)
1143:
1144:     def train_stage3(self, epochs=None):
1145:         """Legacy method - redirects to adaptive training"""
1146:         max_epochs = epochs or self.config.max_stage3_epochs
1147:         min_epochs = self.config.min_stage3_epochs
1148:         return self.train_stage_adaptive(3, max_epochs, min_epochs)

```

■ File: utils\visualization.py

```

1: """
2: Visualization and utility functions
3: """
4:
5: import matplotlib.pyplot as plt
6: import numpy as np
7: import cv2
8: import torch
9: from pathlib import Path
10: from evaluation.metrics import compute_iou
11:
12:
13: def plot_training_history(history, save_path="training_history.png"):
14:     """Plot training curves for all stages"""
15:     fig, axes = plt.subplots(1, 3, figsize=(15, 5))
16:
17:     for idx, (stage, data) in enumerate(history.items()):
18:         if isinstance(data, dict) and "train_loss" in data and data["train_loss"]: # Only plot if
+         stage was executed
19:             axes[idx].plot(data["train_loss"], label="Train", linewidth=2)
20:             axes[idx].plot(data["val_loss"], label="Validation", linewidth=2)
21:             axes[idx].set_title(f"{stage.upper()} Training")
22:             axes[idx].set_xlabel("Epoch")
23:             axes[idx].set_ylabel("Loss")
24:             axes[idx].legend()
25:             axes[idx].grid(True, alpha=0.3)
26:
27:     plt.tight_layout()
28:     plt.savefig(save_path, dpi=300, bbox_inches="tight")
29:     plt.show()
30:
31:
32: def plot_curriculum_analysis(history, save_path="curriculum_analysis.png"):
33:     """Plot curriculum learning analysis including stage transitions and adaptive behavior"""
34:     fig, axes = plt.subplots(2, 2, figsize=(15, 10))
35:
36:     # Plot 1: Stage transition timeline
37:     if "stage_transitions" in history and history["stage_transitions"]:
38:         transitions = history["stage_transitions"]
39:
40:         # Extract transition epochs and reasons
41:         transition_epochs = [t["epoch"] for t in transitions]
42:         transition_stages = [t["from_stage"] + " ? " + t["to_stage"] for t in transitions]
43:         transition_reasons = [t.get("reason", "threshold") for t in transitions]
44:
45:         # Create timeline
46:         y_positions = range(len(transition_epochs))
47:         colors = ['red' if 'patience' in reason else 'green' for reason in transition_reasons]
48:
49:         axes[0, 0].barh(y_positions, transition_epochs, color=colors, alpha=0.7)
50:         axes[0, 0].set_yticks(y_positions)
51:         axes[0, 0].set_yticklabels(transition_stages)
52:         axes[0, 0].set_xlabel("Epoch")
53:         axes[0, 0].set_title("Stage Transition Timeline")
54:         axes[0, 0].grid(True, alpha=0.3)
55:
56:         # Add legend
57:         axes[0, 0].legend(['Patience-based', 'Threshold-based'], loc='lower right')
58:     else:

```

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59:         axes[0, 0].text(0.5, 0.5, "No stage transitions recorded",
60:                         ha='center', va='center', transform=axes[0, 0].transAxes)
61:         axes[0, 0].set_title("Stage Transition Timeline")
62:
63:     # Plot 2: Loss component evolution
64:     if "dynamic_weights" in history and history["dynamic_weights"]:
65:         weight_data = history["dynamic_weights"]
66:         epochs = [entry["epoch"] for entry in weight_data]
67:
68:         # Plot each loss component weight
69:         weight_names = list(weight_data[0]["weights"].keys()) if weight_data else []
70:         for weight_name in weight_names[:5]: # Limit to top 5 for readability
71:             weights = [entry["weights"].get(weight_name, 0) for entry in weight_data]
72:             if any(w > 0.001 for w in weights): # Only plot significant weights
73:                 axes[0, 1].plot(epochs, weights, label=weight_name, linewidth=2, marker='o',
+                 markersize=3)
74:
75:         axes[0, 1].set_xlabel("Global Epoch")
76:         axes[0, 1].set_ylabel("Loss Weight")
77:         axes[0, 1].set_title("Dynamic Loss Weight Evolution")
78:         axes[0, 1].legend()
79:         axes[0, 1].grid(True, alpha=0.3)
80:     else:
81:         axes[0, 1].text(0.5, 0.5, "No dynamic weights recorded",
82:                         ha='center', va='center', transform=axes[0, 1].transAxes)
83:         axes[0, 1].set_title("Dynamic Loss Weight Evolution")
84:
85:     # Plot 3: Curriculum progress indicators
86:     if "curriculum_events" in history and history["curriculum_events"]:
87:         events = history["curriculum_events"]
88:         event_types = {}
89:
90:         for event in events:
91:             event_type = event.get("type", "unknown")
92:             if event_type not in event_types:
93:                 event_types[event_type] = []
94:             event_types[event_type].append(event["epoch"])
95:
96:         # Plot event timeline
97:         y_offset = 0
98:         for event_type, epochs in event_types.items():
99:             axes[1, 0].scatter(epochs, [y_offset] * len(epochs),
100:                               label=event_type, s=50, alpha=0.7)
101:             y_offset += 1
102:
103:         axes[1, 0].set_xlabel("Epoch")
104:         axes[1, 0].set_ylabel("Event Type")
105:         axes[1, 0].set_title("Curriculum Learning Events")
106:         axes[1, 0].legend()
107:         axes[1, 0].grid(True, alpha=0.3)
108:     else:
109:         axes[1, 0].text(0.5, 0.5, "No curriculum events recorded",
110:                         ha='center', va='center', transform=axes[1, 0].transAxes)
111:         axes[1, 0].set_title("Curriculum Learning Events")
112:
113:     # Plot 4: Stage performance comparison
114:     stage_names = ["stage1", "stage2", "stage3"]
115:     stage_performance = {}
116:
117:     for stage_name in stage_names:
118:         if stage_name in history and isinstance(history[stage_name], dict):
119:             stage_data = history[stage_name]
120:             if "val_loss" in stage_data and stage_data["val_loss"]:
121:                 stage_performance[stage_name] = {
122:                     "final_loss": stage_data["val_loss"][-1],
123:                     "best_loss": min(stage_data["val_loss"]),
124:                     "epochs": len(stage_data["val_loss"])
125:                 }
126:
127:     if stage_performance:
128:         stages = list(stage_performance.keys())
129:         final_losses = [stage_performance[s]["final_loss"] for s in stages]
130:         best_losses = [stage_performance[s]["best_loss"] for s in stages]

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131:
132:     x = np.arange(len(stages))
133:     width = 0.35
134:
135:     axes[1, 1].bar(x - width/2, final_losses, width, label='Final Loss', alpha=0.8)
136:     axes[1, 1].bar(x + width/2, best_losses, width, label='Best Loss', alpha=0.8)
137:
138:     axes[1, 1].set_xlabel("Training Stage")
139:     axes[1, 1].set_ylabel("Validation Loss")
140:     axes[1, 1].set_title("Stage Performance Comparison")
141:     axes[1, 1].set_xticks(x)
142:     axes[1, 1].set_xticklabels([s.upper() for s in stages])
143:     axes[1, 1].legend()
144:     axes[1, 1].grid(True, alpha=0.3)
145:
146:     # Add epoch count annotations
147:     for i, stage in enumerate(stages):
148:         epochs = stage_performance[stage]["epochs"]
149:         axes[1, 1].text(i, max(final_losses) * 0.9, f'{epochs} epochs',
150:             ha='center', va='bottom', fontsize=9)
151:     else:
152:         axes[1, 1].text(0.5, 0.5, "No stage performance data",
153:             ha='center', va='center', transform=axes[1, 1].transAxes)
154:         axes[1, 1].set_title("Stage Performance Comparison")
155:
156: plt.tight_layout()
157: plt.savefig(save_path, dpi=300, bbox_inches="tight")
158: plt.close()
159:
160: print(f"Curriculum analysis saved to {save_path}")
161:
162:
163: def visualize_predictions(image, predictions, targets=None, save_path=None):
164:     """Visualize model predictions"""
165:     fig, axes = plt.subplots(2, 3, figsize=(15, 10))
166:
167:     # Original image
168:     if len(image.shape) == 4:
169:         img_np = image[0].permute(1, 2, 0).cpu().numpy()
170:     else:
171:         img_np = image.permute(1, 2, 0).cpu().numpy()
172:
173:     axes[0, 0].imshow(img_np)
174:     axes[0, 0].set_title("Input Image")
175:     axes[0, 0].axis('off')
176:
177:     # Predicted segmentation
178:     if "segmentation" in predictions:
179:         seg_pred = torch.argmax(predictions["segmentation"], dim=1)[0].cpu().numpy()
180:         axes[0, 1].imshow(seg_pred, cmap='tab10')
181:         axes[0, 1].set_title("Predicted Segmentation")
182:         axes[0, 1].axis('off')
183:
184:     # Ground truth segmentation (if available)
185:     if targets and "mask" in targets:
186:         gt_mask = targets["mask"][0].cpu().numpy()
187:         axes[0, 2].imshow(gt_mask, cmap='tab10')
188:         axes[0, 2].set_title("Ground Truth Segmentation")
189:         axes[0, 2].axis('off')
190:
191:     # SDF prediction
192:     if "sdf" in predictions:
193:         sdf_pred = predictions["sdf"][0, 0].cpu().numpy()
194:         im = axes[1, 0].imshow(sdf_pred, cmap='RdBu', vmin=-1, vmax=1)
195:         axes[1, 0].set_title("Predicted SDF")
196:         axes[1, 0].axis('off')
197:         plt.colorbar(im, ax=axes[1, 0])
198:
199:     # Polygon visualization
200:     if "polygons" in predictions:
201:         poly_vis = visualize_polygons(
202:             predictions["polygons"][0],
203:             predictions["polygon_validity"][0],

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204:         image_size=(256, 256)
205:     )
206:     axes[1, 1].imshow(poly_vis)
207:     axes[1, 1].set_title("Predicted Polygons")
208:     axes[1, 1].axis('off')
209:
210:     # 3D voxel slice
211:     if "voxels_pred" in predictions:
212:         voxels = torch.sigmoid(predictions["voxels_pred"])[0].cpu().numpy()
213:         # Show middle slice
214:         mid_slice = voxels[voxels.shape[0]//2]
215:         axes[1, 2].imshow(mid_slice, cmap='viridis')
216:         axes[1, 2].set_title("3D Voxels (Mid Slice)")
217:         axes[1, 2].axis('off')
218:
219:     plt.tight_layout()
220:
221:     if save_path:
222:         plt.savefig(save_path, dpi=300, bbox_inches="tight")
223:
224:     plt.show()
225:
226:
227: def visualize_polygons(polygons, validity, image_size=(256, 256), threshold=0.5):
228:     """Visualize predicted polygons"""
229:     vis_img = np.zeros((*image_size, 3), dtype=np.uint8)
230:
231:     for poly_idx, (polygon, valid_score) in enumerate(zip(polygons, validity)):
232:         if valid_score > threshold:
233:             # Convert to image coordinates
234:             points = polygon.cpu().numpy() * np.array(image_size)
235:
236:             # Remove zero-padded points
237:             valid_points = points[points.sum(axis=1) > 0]
238:
239:             if len(valid_points) >= 3:
240:                 points_int = valid_points.astype(np.int32)
241:
242:                 # Different colors for different polygons
243:                 color = plt.cm.tab10(poly_idx % 10)[:3]
244:                 color = tuple(int(c * 255) for c in color)
245:
246:                 cv2.polylines(vis_img, [points_int], True, color, 2)
247:
248:                 # Add polygon index
249:                 center = points_int.mean(axis=0).astype(int)
250:                 cv2.putText(vis_img, str(poly_idx), tuple(center),
251:                             cv2.FONT_HERSHEY_SIMPLEX, 0.5, (255, 255, 255), 1)
252:
253:     return vis_img
254:
255:
256: def save_model_outputs(predictions, output_dir, sample_id):
257:     """Save all model outputs for detailed analysis"""
258:     output_dir = Path(output_dir)
259:     output_dir.mkdir(exist_ok=True)
260:
261:     sample_dir = output_dir / sample_id
262:     sample_dir.mkdir(exist_ok=True)
263:
264:     # Save segmentation
265:     if "segmentation" in predictions:
266:         seg_pred = torch.argmax(predictions["segmentation"], dim=1)[0].cpu().numpy()
267:         cv2.imwrite(str(sample_dir / "segmentation.png"), seg_pred * 50)
268:
269:     # Save SDF
270:     if "sdf" in predictions:
271:         sdf_pred = predictions["sdf"][0, 0].cpu().numpy()
272:         sdf_normalized = ((sdf_pred + 1) * 127.5).astype(np.uint8)
273:         cv2.imwrite(str(sample_dir / "sdf.png"), sdf_normalized)
274:
275:     # Save attributes
276:     if "attributes" in predictions:

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277:         attrs = predictions["attributes"][0].cpu().numpy()
278:         np.save(sample_dir / "attributes.npy", attrs)
279:
280:     # Save polygons
281:     if "polygons" in predictions:
282:         polygons = predictions["polygons"][0].cpu().numpy()
283:         validity = predictions["polygon_validity"][0].cpu().numpy()
284:
285:         np.save(sample_dir / "polygons.npy", polygons)
286:         np.save(sample_dir / "polygon_validity.npy", validity)
287:
288:     # Save voxels
289:     if "voxels_pred" in predictions:
290:         voxels = torch.sigmoid(predictions["voxels_pred"][0]).cpu().numpy()
291:         np.save(sample_dir / "voxels.npy", voxels)
292:
293:
294: def create_comparison_grid(input_images, predictions, targets=None, num_samples=4):
295:     """Create a comparison grid showing inputs, predictions, and targets"""
296:     fig, axes = plt.subplots(num_samples, 4, figsize=(16, 4 * num_samples))
297:
298:     for i in range(min(num_samples, len(input_images))):
299:         # Input image
300:         img = input_images[i].permute(1, 2, 0).cpu().numpy()
301:         axes[i, 0].imshow(img)
302:         axes[i, 0].set_title(f"Sample {i+1}: Input")
303:         axes[i, 0].axis('off')
304:
305:         # Predicted segmentation
306:         seg_pred = torch.argmax(predictions["segmentation"][i], dim=0).cpu().numpy()
307:         axes[i, 1].imshow(seg_pred, cmap='tab10')
308:         axes[i, 1].set_title("Predicted Seg")
309:         axes[i, 1].axis('off')
310:
311:         # Ground truth segmentation (if available)
312:         if targets and "mask" in targets:
313:             gt_mask = targets["mask"][i].cpu().numpy()
314:             axes[i, 2].imshow(gt_mask, cmap='tab10')
315:             axes[i, 2].set_title("GT Segmentation")
316:         else:
317:             axes[i, 2].text(0.5, 0.5, "No GT", ha='center', va='center',
318:                             transform=axes[i, 2].transAxes)
319:             axes[i, 2].set_title("GT Segmentation")
320:             axes[i, 2].axis('off')
321:
322:         # Polygon overlay
323:         poly_vis = visualize_polygons(
324:             predictions["polygons"][i],
325:             predictions["polygon_validity"][i]
326:         )
327:         axes[i, 3].imshow(poly_vis)
328:         axes[i, 3].set_title("Predicted Polygons")
329:         axes[i, 3].axis('off')
330:
331:     plt.tight_layout()
332:     return fig
333:
334:
335: def analyze_failure_cases(predictions, targets, threshold_iou=0.5):
336:     """Analyze failure cases for debugging"""
337:     failure_indices = []
338:
339:     for i, (pred_seg, gt_mask) in enumerate(zip(predictions["segmentation"], targets["mask"])):
340:         seg_pred = torch.argmax(pred_seg, dim=0)
341:         iou = compute_iou(seg_pred, gt_mask)
342:
343:         if iou < threshold_iou:
344:             failure_indices.append({
345:                 "index": i,
346:                 "iou": iou,
347:                 "pred_classes": torch.unique(seg_pred).tolist(),
348:                 "gt_classes": torch.unique(gt_mask).tolist()
349:             })

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350:
351:     return failure_indices
352:
353:
354: class ProgressiveVisualization:
355:     """Track and visualize training progress"""
356:
357:     def __init__(self, save_dir="./training_progress"):
358:         self.save_dir = Path(save_dir)
359:         self.save_dir.mkdir(exist_ok=True)
360:
361:     def log_epoch_results(self, epoch, stage, predictions, targets, sample_image):
362:         """Log results for a specific epoch"""
363:         epoch_dir = self.save_dir / f"{stage}_epoch_{epoch}"
364:         epoch_dir.mkdir(exist_ok=True)
365:
366:         # Save prediction visualization
367:         fig = plt.figure(figsize=(12, 8))
368:         visualize_predictions(sample_image, predictions, targets)
369:         plt.savefig(epoch_dir / "predictions.png", dpi=150, bbox_inches="tight")
370:         plt.close()
371:
372:         # Save individual outputs
373:         save_model_outputs(predictions, epoch_dir, "sample")
374:
375:     def create_training_animation(self, stage, metric_name="total_loss"):
376:         """Create animated GIF showing training progress"""
377:         # This would create an animation of training progress
378:         # Implementation depends on having saved epoch results
379:         pass
380:
381:
382: def compute_architectural_metrics(predictions, image_size=(256, 256)):
383:     """Compute architecture-specific metrics"""
384:     metrics = {}
385:
386:     if "segmentation" in predictions:
387:         seg_pred = torch.argmax(predictions["segmentation"], dim=1)[0]
388:
389:         # Room count
390:         room_mask = (seg_pred == 0).cpu().numpy().astype(np.uint8)
391:         contours, _ = cv2.findContours(room_mask, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
392:         room_count = len([c for c in contours if cv2.contourArea(c) > 100])
393:         metrics["room_count"] = room_count
394:
395:         # Wall connectivity
396:         wall_mask = (seg_pred == 1).cpu().numpy().astype(np.uint8)
397:         wall_components = cv2.connectedComponents(wall_mask)[0] - 1 # Subtract background
398:         metrics["wall_components"] = max(0, wall_components)
399:
400:         # Door and window counts
401:         door_pixels = (seg_pred == 2).sum().item()
402:         window_pixels = (seg_pred == 3).sum().item()
403:         metrics["door_pixels"] = door_pixels
404:         metrics["window_pixels"] = window_pixels
405:
406:     if "polygons" in predictions:
407:         validity = predictions["polygon_validity"][0]
408:         valid_polygons = (validity > 0.5).sum().item()
409:         metrics["valid_polygon_count"] = valid_polygons
410:
411:         # Average polygon area
412:         polygons = predictions["polygons"][0]
413:         areas = []
414:         for poly_idx, (polygon, valid) in enumerate(zip(polygons, validity)):
415:             if valid > 0.5:
416:                 # Compute polygon area using shoelace formula
417:                 points = polygon.cpu().numpy() * np.array(image_size)
418:                 valid_points = points[points.sum(axis=1) > 0]
419:                 if len(valid_points) >= 3:
420:                     area = compute_polygon_area(valid_points)
421:                     areas.append(area)
422:

```



```

423:         metrics["avg_polygon_area"] = np.mean(areas) if areas else 0.0
424:
425:     return metrics
426:
427:
428: def compute_polygon_area(points):
429:     """Compute polygon area using shoelace formula"""
430:     if len(points) < 3:
431:         return 0.0
432:
433:     x = points[:, 0]
434:     y = points[:, 1]
435:
436:     # Shoelace formula
437:     area = 0.5 * abs(sum(x[i] * y[i+1] - x[i+1] * y[i] for i in range(-1, len(x)-1)))
438:     return area
439:
440:
441: def create_model_summary_report(model, sample_input, save_path="model_summary.txt"):
442:     """Create detailed model summary report"""
443:     with open(save_path, "w") as f:
444:         f.write("Neural-Geometric 3D Model Generator - Model Summary\n")
445:         f.write("=" * 60 + "\n\n")
446:
447:         # Model architecture
448:         f.write("MODEL ARCHITECTURE:\n")
449:         f.write("-" * 20 + "\n")
450:
451:         total_params = sum(p.numel() for p in model.parameters())
452:         trainable_params = sum(p.numel() for p in model.parameters() if p.requires_grad)
453:
454:         f.write(f"Total parameters: {total_params:},\n")
455:         f.write(f"Trainable parameters: {trainable_params:},\n")
456:         f.write(f"Model size: {total_params * 4 / 1024 / 1024:.2f} MB\n\n")
457:
458:         # Component breakdown
459:         f.write("COMPONENT PARAMETERS:\n")
460:         f.write("-" * 25 + "\n")
461:
462:         encoder_params = sum(p.numel() for p in model.encoder.parameters())
463:         seg_params = sum(p.numel() for p in model.seg_head.parameters())
464:         attr_params = sum(p.numel() for p in model.attr_head.parameters())
465:         sdf_params = sum(p.numel() for p in model.sdf_head.parameters())
466:         dvx_params = sum(p.numel() for p in model.dvx.parameters())
467:         ext_params = sum(p.numel() for p in model.extrusion.parameters())
468:
469:         f.write(f"Encoder: {encoder_params:}, ({encoder_params/total_params*100:.1f}%) \n")
470:         f.write(f"Segmentation Head: {seg_params:}, ({seg_params/total_params*100:.1f}%) \n")
471:         f.write(f"Attribute Head: {attr_params:}, ({attr_params/total_params*100:.1f}%) \n")
472:         f.write(f"SDF Head: {sdf_params:}, ({sdf_params/total_params*100:.1f}%) \n")
473:         f.write(f"DVX Module: {dvx_params:}, ({dvx_params/total_params*100:.1f}%) \n")
474:         f.write(f"Extrusion Module: {ext_params:}, ({ext_params/total_params*100:.1f}%) \n\n")
475:
476:         # Forward pass analysis
477:         f.write("FORWARD PASS ANALYSIS:\n")
478:         f.write("-" * 25 + "\n")
479:
480:         model.eval()
481:         with torch.no_grad():
482:             predictions = model(sample_input)
483:
484:             for key, value in predictions.items():
485:                 if torch.is_tensor(value):
486:                     f.write(f"{key}: {list(value.shape)} - {value.dtype} \n")
487:                 else:
488:                     f.write(f"{key}: {type(value)} \n")
489:
490:         print(f"Model summary saved to {save_path}")
491:
492:
493: def debug_gradient_flow(model, loss):
494:     """Debug gradient flow through the model"""
495:     print("Gradient Flow Analysis:")

```

```

496:     print("-" * 30)
497:
498:     total_norm = 0
499:     component_norms = {}
500:
501:     for name, param in model.named_parameters():
502:         if param.grad is not None:
503:             param_norm = param.grad.norm().item()
504:             total_norm += param_norm ** 2
505:
506:             # Group by component
507:             component = name.split('.')[0]
508:             if component not in component_norms:
509:                 component_norms[component] = 0
510:             component_norms[component] += param_norm ** 2
511:
512:     total_norm = total_norm ** 0.5
513:
514:     print(f"Total gradient norm: {total_norm:.4f}")
515:     print("Component gradient norms:")
516:
517:     for component, norm in component_norms.items():
518:         norm = norm ** 0.5
519:         print(f"    {component}: {norm:.4f} ({norm/total_norm*100:.1f}%)" )
520:
521:
522: def create_3d_visualization(voxels, output_path="3d_preview.png"):
523:     """Create 3D visualization of voxel prediction"""
524:     try:
525:         import matplotlib.pyplot as plt
526:         from mpl_toolkits.mplot3d import Axes3D
527:
528:         # Convert to binary
529:         if isinstance(voxels, torch.Tensor):
530:             voxels = voxels.cpu().numpy()
531:
532:         binary_voxels = voxels > 0.5
533:
534:         # Get occupied voxel coordinates
535:         occupied = np.where(binary_voxels)
536:
537:         if len(occupied[0]) == 0:
538:             print("No occupied voxels to visualize")
539:             return
540:
541:         # Create 3D plot
542:         fig = plt.figure(figsize=(10, 8))
543:         ax = fig.add_subplot(111, projection='3d')
544:
545:         # Plot occupied voxels
546:         ax.scatter(occupied[0], occupied[1], occupied[2],
547:                   c=occupied[2], cmap='viridis', s=1, alpha=0.6)
548:
549:         ax.set_xlabel('X')
550:         ax.set_ylabel('Y')
551:         ax.set_zlabel('Z')
552:         ax.set_title('3D Voxel Occupancy')
553:
554:         plt.savefig(output_path, dpi=150, bbox_inches="tight")
555:         plt.close()
556:
557:         print(f"3D visualization saved to {output_path}")
558:
559:     except ImportError:
560:         print("3D visualization requires matplotlib with 3D support")

```
