Automatic Impression Generation for Positron Emission Tomography Reports using Lightweight Adaptation of Pretrained Large Language Models

Nuohao Liu, Xin Tie, Xiaogeng Liu

Radiology Report

Radiological Examination

Reading Physician

EXAM: PET CT SKULL BASE TO THIGH.
HISTORY: New diagnosis of lymphoma, 3-week history of cough, fevers, night sweats, and 8-pound weight loss.
TECHNIQUE: In a rested and fastir state, the patient was injected with F-18 FDG. The patient was imaged after an approximate 1 hour uptake phase delay using a dedicated dual modality PET/CT scanner with concurrent noncontrast CT scan data acquisition used for anatomic correlation and coregistration, and for attenuation eorvection. Images were processed with and without attenuation correction and with the generation of standardized uptake values (SUVs) as appropriate. The study is reviewed with the CT images, PBT images and the fused PEL/CT images presented in the standard three projections, along with the MIP 3-D rotational images.
COMPARISON: [DATE] neck and chest CT, [DATE] mediastinal mass biopsy
FINDINGS:
Skull base/neck: Probable physiologic activity is noted in the nasopharynx. Uptake in the floor of the mouth may be related to artifact from dental hardware. Hypermetabolic nodes are present in both supraclavicular regions, contiguous with superior mediastinal adenopathy.
Chest: There is bilateral hypermetabolic mediastinal lymphadenopathy. For reference, the largest left prevascular mass of confluent adenopathy has a maximum SUV of 13.6. No hypermetabolic hilar adenopathy is identified. No lung lesions are identified. No hypermetabolic axillary nodes.
Abdomen/pelvis/proximal thighs: Clustered hypermetabolic masses are noted in the left upper quadrant at the level of the splenic hilum and adjacent to the stomach and pancreatic tail. Maximum SUV is 12.5. There is presumed physiologic activity along both renal collecting systems and ureters and bladder as well as in the ascending colon. Activity in the right retroperitoneum is at the level of the mid ureter and is favored to be ureteral in origin. Small soft tissue densities are noted on noncontrast CT images in the retroperitoneum, suspicious for adenopathy; however, they are not hypermetabolic.
Musculoskeletal: No focal hypermetabolic lesions are identified in the visualized portions of the skeleton.
IMPRESSIONS:
[1] Intensely hypermetabolic superior mediastinal and bilateral supraclavicular adenopathy.
[2] Intensely hypermetabolic clustered lymph nodes in the region of the splenic hilum.
[3] Non-hypermetabolic retroperitoneal adenopathy is suspected. Correlation with a diagnostic CT of the abdomen and pelvis with IV and oral contrast is recommended.

Radiology Report

Healthcare Team

Patient

Clinical Whole-body PET Reports

BACKGROUND INFORMATION

[AGE] years old patient with Gleason 3+4 prostate adenocarcinoma diagnosed in [DATE]. Patient is referred for initial staging.

Report for a PET/CT skull base to thigh exam

Clinical Whole-body PET Reports

BACKGROUND INFORMATION

[AGE] years old patient with Gleason 3+4 prostate adenocarcinoma diagnosed in [DATE]. Patient is referred for initial staging.

FINDINGS

Physiologic background liver standardized uptake value (...)
Visualized head/neck: Physiologic uptake of the lacrimal and salivary glands. (...)
Head / neck lymph nodes: No suspicious head/neck lymph nodes.
Chest: No lung nodules or abnormal uptake. No pleural or pericardial effusion. (...)
Hepatobiliary: No abnormal uptake. Photogenic left hepatic cyst. (...)
Spleen / pancreas / adrenals: No abnormal splenic uptake. (...)
Kidneys / bladder: No abnormal uptake. (...)
Bowel / peritoneum: No suspicious bowel uptake or abnormality. (...)
Pelvic organs: Bilateral foci of uptake bilaterally in the peripheral zone of the prostate, (...)
Abdominopelvic lymph nodes: No definitive suspicious abdominopelvic lymph nodes. (...)
Musculoskeletal / soft tissues / skin: No suspicious lesions. (...)

Report for a PET/CT skull base to thigh exam

Clinical Whole-body PET Reports

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IMPRESSION

[1] Bilateral focal of uptake in the prostate consistent with known adenocarcinoma.
[2] No definitive evidence for metastatic disease. Several foci of uptake in the region of the lower lumbar spine, are favored to represent benign uptake, as detailed. Follow-up may be helpful.

Report for a PET/CT skull base to thigh exam

Clinical Whole-body PET Reports

- Referring physicians primarily rely on the **impression** section for clinical decision-making and management

BACKGROUND INFORMATION

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Report for a PET/CT skull base to thigh exam

Clinical Whole-body PET Reports

- Accuracy and completeness

FINDINGS

Physiologic background liver standardized uptake value (SUV mean and SUV max) reported for comparison between PET studies: 2.7 and 3.5, previously 2.4 and 3.0.
Visualized head/neck: Dental hardware artifact limiting evaluation of adjacent structures. Postsurgical changes following multiple resections and reconstructions. Intense uptake of the floor the mouth extending posteriorly to the base of the right tongue, right parapharyngeal tissues, and adjacent palatal flap, which correlate with areas enhancement on MR [DATE] and is consistent with biopsy-proven disease recurrence. For example, the SUV max is 7.0 in the surgical bed (PET/CT axial image 25), and, the SUV max is 9.4 at the base of the tongue (PET/CT axial image 32). There is some mass effect on the right internal carotid artery, correlating with chronically occluded vessels seen on recent MR.
Focal uptake associated with left mandibular teeth, approximately at the location of tooth #13, is likely inflammatory/reactive due to recent tooth extraction (PET/CT axial image 30). Compared to PET CT [DATE], interval placement of tracheostomy tube, which is in place with surrounding inflammatory/reactive uptake. Elsewhere, physiologic uptake in the visualized portions of the brain, extraocular muscles, and salivary glands.
Head/neck lymph nodes: No suspicious head/neck lymph nodes.
Lungs: Atelectatic banding/scarring in the right lower lobe. Compared to PET/CT [DATE], there is a new pulmonary nodule in the right lower lobe measuring 2.1 x 1.4 cm with SUV max 4.6 (PET/CT axial image 103). There are other new sub-centimeter pulmonary nodules scattered in the right lung, for example, there is a 9 mm pulmonary nodule in the posterior right lung with mild radiotracer uptake (SUV max 1.4, PET/CT axial image 80). New non radiotracer avid 3 mm pulmonary nodule in the posterior lung base (PET/CT axial image 105). Atelectatic banding/scarring in the posterior left lung base.
Pleura/pericardium: No pleural or pericardial effusion.
Thoracic lymph nodes: Mild uptake in few mediastinal lymph nodes, which are nonspecific but favored to be reactive, for example:
- Para-aortic lymph node, 0.7 x 0.5 cm, SUV max 2.0 (PET/CT axial image 79)
- Subcarinal lymph node, 1.1 x 0.67 m, SUV max 2.9 (PET/CT axial image 84).
Other chest findings: Physiologic myocardial uptake. Inflammatory/reactive uptake in the distal esophagus. Mild gynecomastia.
Hepatobiliary: No abnormal uptake. Spleen: No abnormal uptake. Pancreas: No abnormal uptake. Adrenals: Within normal limits.
Kidneys/bladder: No abnormal uptake. Physiologically excreted tracer activity within the renal collecting system and urinary bladder.
Bowel/peritoneum: Redemonstrated gastrostomy tube is appropriately positioned with surrounding reactive uptake. No suspicious uptake. Areas of bowel uptake are probably inflammatory/physiologic, and benign. Compared to PET/CT [DATE], resolved postsurgical pneumoperitoneum with scarring in the subcutaneous fat in the anterior body wall (PET/CT axial image 185).
Pelvic organs: No abnormal uptake. Vasectomy clips.
Abdominopelvic lymph nodes: No suspicious abdominopelvic lymph nodes.
Musculoskeletal/soft tissues/skin: Mild uptake associated with the right body of the ramus correlating with loss of normal marrow signal on MR [DATE] and suspicious for osseous metastasis. Postsurgical changes of the right proximal humerus.
Other: Scattered aortoiliac calcifications.

Distill

IMPRESSION

[1] FDG PET/CT demonstrates intense uptake of the floor the mouth extending posteriorly to the base of the right tongue, right parapharyngeal tissues, and adjacent palatal flap, which correlates with areas enhancement on MR [DATE] and is consistent with biopsy-proven disease recurrence.

[2] Mild uptake associated with the right body of the ramus correlating with loss of normal marrow signal on MR [DATE] and suspicious for osseous metastasis.

[3] Focal uptake associated with left mandibular teeth, approximately at the location of tooth #13, is likely inflammatory/reactive due to recent tooth extraction. Correlate with physical exam.

[4] Compared to PET/CT [DATE], there are new pulmonary nodules in the lungs, as detailed in findings. Moderate uptake associated with the dominant nodule in the right lower lobe is suspicious for metastasis versus second primary malignancy.

[5] Mild uptake in few mediastinal lymph nodes is nonspecific but favored to be reactive. Attention on follow-up.

Clinical Whole-body PET Reports

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Other: Scattered aortoiliac calcifications.

Distill

Time-consuming and error-prone

IMPRESSION

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Language Models for Automatic Impression Generation

- Large language models (LLMs) have the potential to **accelerate** the **drafting** of PET impressions

- There have been commercial products for automatic impression generation
  - **Streamline** clinical reporting workflows
  - **Reduce burnout** among reading physicians

- **Few studies** focused on impression generation for whole-body PET reports

What Makes Automatic PET Impression Generation Different?

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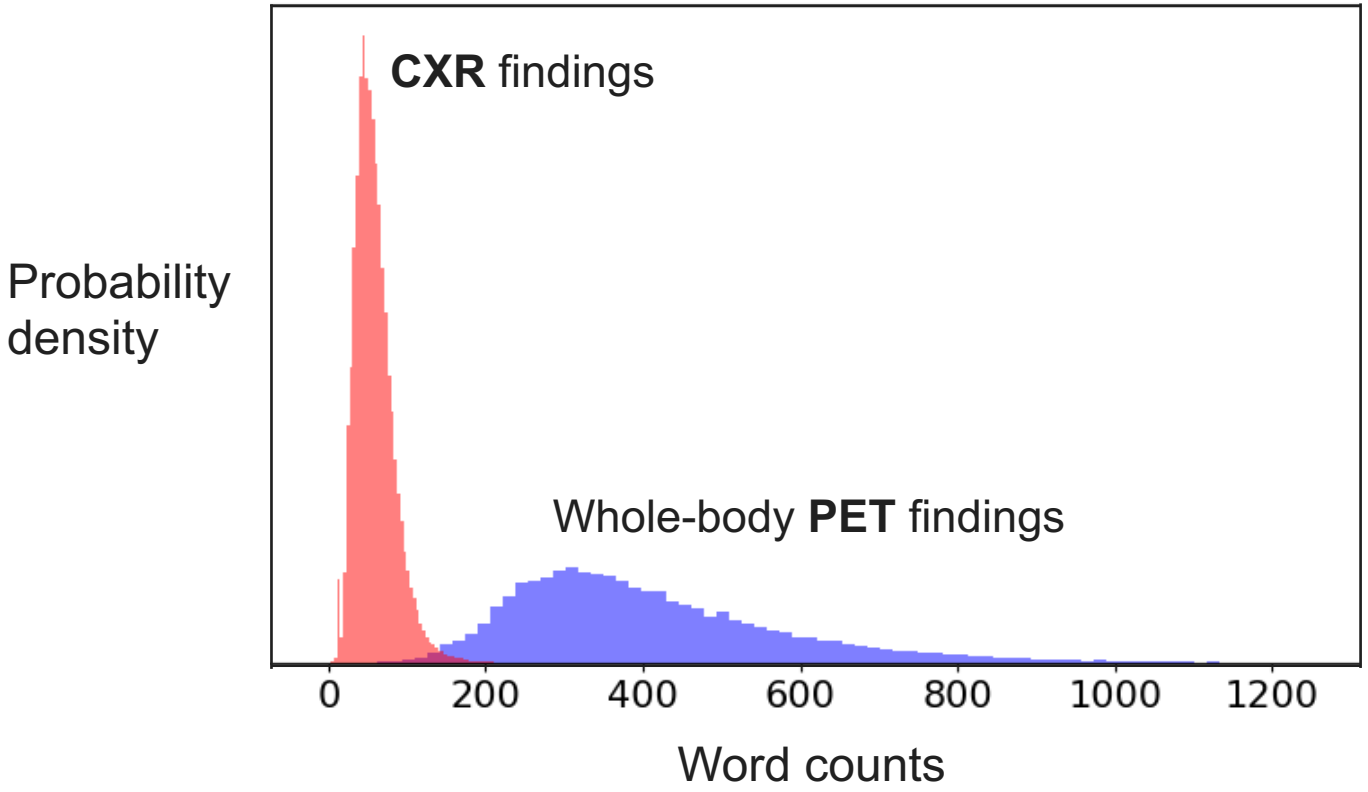
- **Length**
  - 250-500 words in the findings section



What Makes Automatic PET Impression Generation Different?

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- **Complexity**
  - Observation across multiple anatomical regions

FINDINGS

Physiologic background liver standardized uptake value (SUV mean and SUV max) (…)
Visualized head/neck: Physiologic uptake in the visualized portions of the brain (…)
Head/neck lymph nodes: Interval decreased size and FDG activity (…)
-Right level IIb, 1.2 x 0.7 cm transaxially, SUV max 5.5, previously 1.6 x 0.7 cm, SUV max 6.2 (…)
Lungs / Pleura / pericardium: No suspicious lung nodules or abnormal uptake. (…)
Thoracic lymph nodes: Near complete resolution of supraclavicular/upper mediastinal (…)
Other chest findings: Physiologic myocardial uptake. Coronary artery calcifications. (…)
Hepatobiliary: No abnormal uptake..
Spleen / Pancreas / Adrenals: No abnormal uptake. (…)
Kidneys / bladder: No abnormal uptake. Physiologically excreted tracer activity (…)
Bowel / peritoneum: No suspicious bowel uptake or abnormality.
Pelvic organs: No abnormal uptake..
Abdominopelvic lymph nodes: Interval increased FDG uptake in an aortocaval lymph node (…)
Musculoskeletal / soft tissues / skin: No suspicious osseous lesions.

Parameter-Efficient Fine-tuning (PEFT)

- Adapting LLMs for PET report summarization can be quite **expensive**
- PEFT has been proven **effective** in adapting pre-trained LLMs for various downstream applications
  - Most evaluated tasks are classification, multiple-choice QA
- It remains unclear how well these techniques perform in the task of radiology report summarization with **long input sequences**

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Purpose

- To evaluate the effectiveness of PEFT in fine-tuning LLMs for summarizing PET findings

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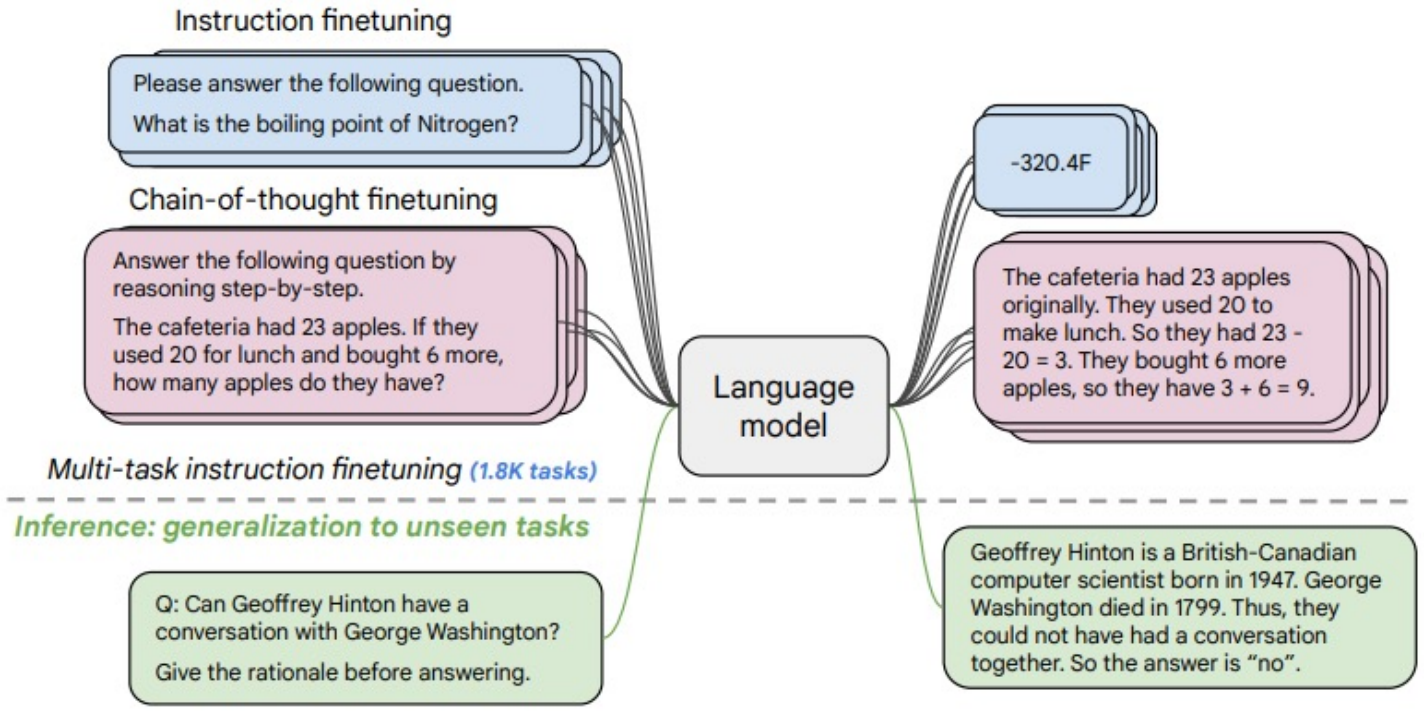
Dataset

- **37,370** retrospective PET reports from UW healthcare system between Jan 2010 and Jan 2023.
  - **65** different physicians
  - Internal testing: 4000 reports
  - Training: 31,370 reports; Validation: 2000 reports

Backbone Model

- FLAN-T5

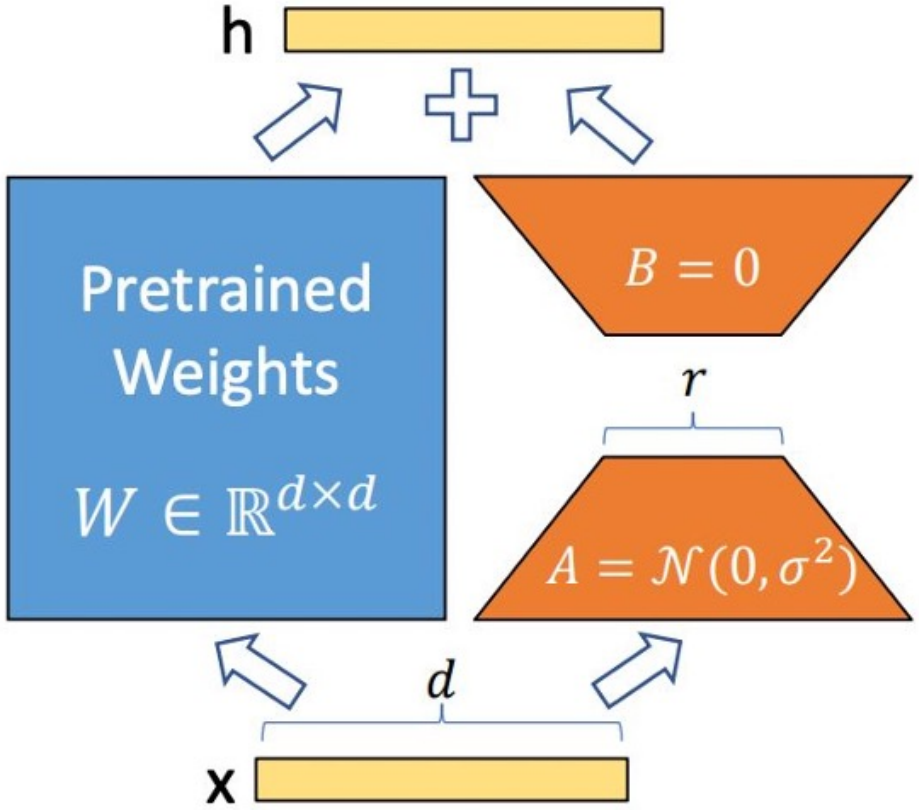


Fine-tuning Methods

- Full fine-tuning

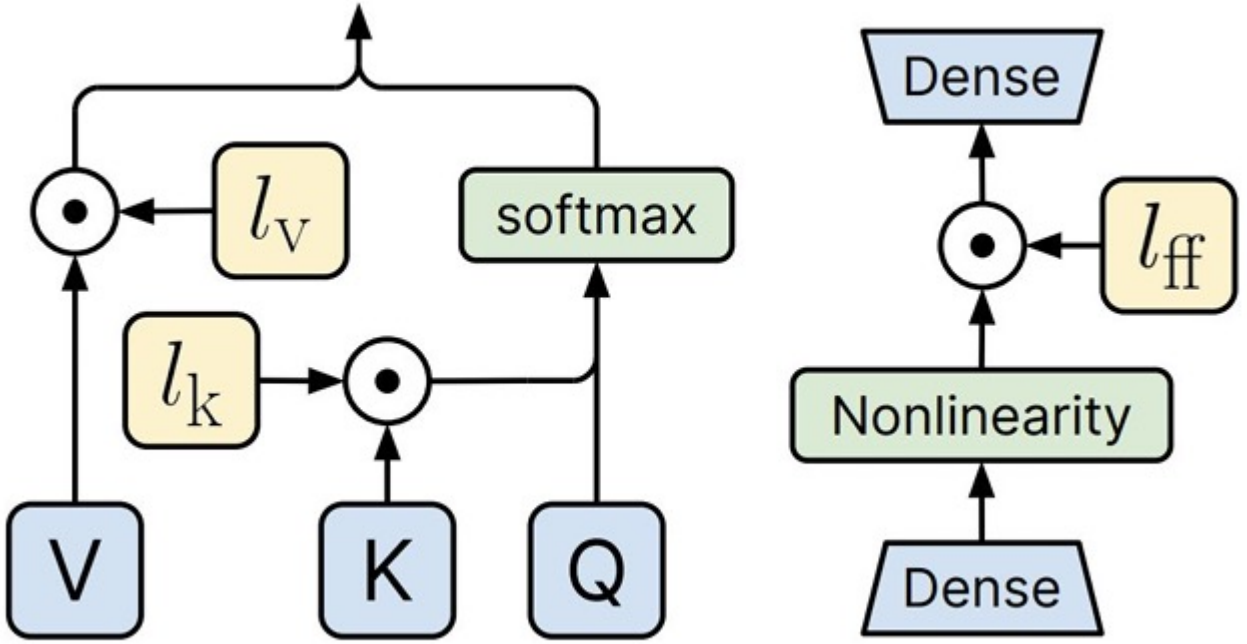
Fine-tuning Methods

- Full fine-tuning
- PEFT
  - LoRA



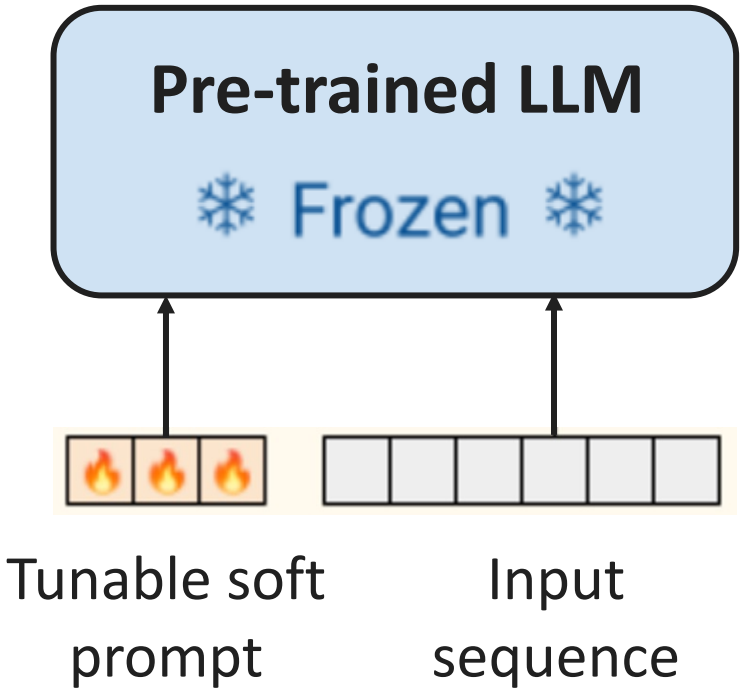
Fine-tuning Methods

- Full fine-tuning
- PEFT
  - LoRA
  - IA3



Fine-tuning Methods

- Full fine-tuning
- PEFT
  - LoRA
  - IA3
  - Prompt tuning



Experiments

- Compare the performance of PEFT methods against full fine-tuning
  - FLAN-T5-large (783 M)
  - LORA: 4.7 M
  - IA3: 0.2 M
  - Prompt tuning: 0.2 M

- Select the best PEFT method and scale to a larger model
  - FLAN-T5-XL (3 B)

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Implementation Details

- Teacher-forcing algorithm
  - Input: report findings and patient information
  - Reference: clinical impressions
  - Negative log-likelihood loss
- AdamW optimizer
- Beam search decoding algorithm
  - Number of beams: 4
  - Trigram Blocking

Quantitative Results

Evaluation Metrics	Models			
	Flan-T5-large (**full fine-tuning**)	Flan-T5-large (**LoRA**)	Flan-T5-large (**IA3**)	Flan-T5-large (**Prompt-Tuning**)
ROUGE-1	54.1	52.0	47.3	6.5
ROUGE-2	30.9	28.7	24.9	1.5
ROUGE-3	20.4	18.4	15.7	0.5
ROUGE-L	50.8	48.6	44.1	5.8
BLEU	24.7	22.8	19.2	0.4
CHRF	42.2	40.4	35.6	3.9

Quantitative Results

Evaluation Metrics	Models			
	Flan-T5-large (**full fine-tuning**)	Flan-T5-large (**LoRA**)	Flan-T5-large (**IA3**)	Flan-T5-large (**Prompt-Tuning**)
BERT-score	0.747	0.735	0.713	0.465
Mover-score	0.607	0.600	0.587	0.498

Quantitative Results

Evaluation Metrics	Models			
	Flan-T5-large (**full fine-tuning**)	Flan-T5-large (**LoRA**)	Flan-T5-large (**IA3**)	Flan-T5-large (**Prompt-Tuning**)
BARTScore *	-1.56 [-1.58, -1.55]	-1.63 [-1.65, -1.62]	-1.74 [-1.75, -1.72]	-3.16 [-3.19, -3.14]

* BARTScore has been adapted to the PET domain

Quantitative Results

Evaluation Metrics	Models	
	Flan-T5-large (full fine-tuning)	Flan-T5-XL (LoRA)
ROUGE-1	54.1	53.6
ROUGE-2	30.9	30.2
ROUGE-3	20.4	19.8
ROUGE-L	50.8	50.3
BLEU	24.7	24.4
CHRF	42.2	42.2
BERT-score	0.747	0.743
Mover-score	0.607	0.605
BARTScore *	-1.56	-1.58

Sample Case

Original Clinical Impression	LLM Impression (Flan-T5-large, full finetuning)
[1] FDG PET/CT demonstrates short-term stability of the solitary nodule within the right upper lobe, which has only minimal associated FDG uptake, not elevated above mediastinal blood pool. Given the lack of significant FDG avidity, and the suggestion of macroscopic fat within the nodule on prior diagnostic chest CT, a benign lesion such as a pulmonary hamartoma is a consideration. Could consider short-term follow-up diagnostic CT chest in 3-6 months to assess for interval change. [2] No evidence of suspected FDG avid local nodal mediastinal/hilar or distant metastatic disease. [3] Mildly lobulated nodular soft tissue in the subareolar right breast, without significant FDG avidity. Could correlate with prior mammography, if available. If not, screening mammography is recommended.	[1] FDG PET/CT demonstrates a 1.2 x 1.3 cm subpleural oval-shaped solid nodule within the anteroinferior right upper lobe with mild associated FDG uptake. This is nonspecific by PET criteria, with differential including neoplastic versus infectious/inflammatory etiologies. Recommend thoracic CT follow-up to assess for interval change in size. [2] No evidence of FDG avid local nodal or distant metastatic disease. [3] Redemonstration of a mildly lobulated nodular area of soft tissue within the subareolar right breast, unchanged compared to [DATE]. This does not appear to be hypermetabolic and is favored to represent a benign entity such as a sebaceous cyst.

Sample Case

Original Clinical Impression	LLM Impression (Flan-T5-large, LORA finetuning)
[1] FDG PET/CT demonstrates short-term stability of the solitary nodule within the right upper lobe, which has only minimal associated FDG uptake, not elevated above mediastinal blood pool. Given the lack of significant FDG avidity, and the suggestion of macroscopic fat within the nodule on prior diagnostic chest CT, a benign lesion such as a pulmonary hamartoma is a consideration. Could consider short-term follow-up diagnostic CT chest in 3-6 months to assess for interval change. [2] No evidence of suspected FDG avid local nodal mediastinal/hilar or distant metastatic disease. [3] Mildly lobulated nodular soft tissue in the subareolar right breast, without significant FDG avidity. Could correlate with prior mammography, if available. If not, screening mammography is recommended.	[1] FDG PET/CT demonstrates a subpleural oval-shaped solid nodule within the anteroinferior right upper lobe immediately superior to the right minor fissure, with mild associated FDG uptake, which is nonspecific by PET criteria for an infectious/inflammatory process versus low-grade primary lung malignancy. Recommend tissue sampling for further evaluation as clinically indicated. [2] No evidence of FDG avid local nodal or distant metastatic disease. [3] Redemonstration of a mildly lobulated nodular area of soft tissue within the subareolar right breast, unchanged compared to [DATE]. This does not appear to have significant FDG activity, and is favored to represent a benign etiology.

Sample Case

Original Clinical Impression	LLM Impression (Flan-T5-large, IA3 finetuning)
[1] FDG PET/CT demonstrates short-term stability of the solitary nodule within the right upper lobe, which has only minimal associated FDG uptake, not elevated above mediastinal blood pool. Given the lack of significant FDG avidity, and the suggestion of macroscopic fat within the nodule on prior diagnostic chest CT, a benign lesion such as a pulmonary hamartoma is a consideration. Could consider short-term follow-up diagnostic CT chest in 3-6 months to assess for interval change. [2] No evidence of suspected FDG avid local nodal mediastinal/hilar or distant metastatic disease. [3] Mildly lobulated nodular soft tissue in the subareolar right breast, without significant FDG avidity. Could correlate with prior mammography, if available. If not, screening mammography is recommended.	[1] FDG PET/CT demonstrates a subpleural oval-shaped solid nodule within the anteroinferior right upper lobe immediately superior to the right minor fissure, with mild associated FDG uptake, consistent with known **primary lung malignancy.** [2] No evidence of FDG avid distant metastatic disease. [3] Redemonstration of a mildly lobulated nodular area of soft tissue within the subareolar right breast, unchanged compared to [DATE]. This does not appear to have associated hypermetabolism. Recommend clinical correlation.

Patient history: [Age]-year-old [SEX] with a history of a stage III metastatic left breast cancer. No primary lung malignant

Sample Case

Original Clinical Impression	LLM Impression (Flan-T5-large, prompt finetuning)
[1] FDG PET/CT demonstrates short-term stability of the solitary nodule within the right upper lobe, which has only minimal associated FDG uptake, not elevated above mediastinal blood pool. Given the lack of significant FDG avidity, and the suggestion of macroscopic fat within the nodule on prior diagnostic chest CT, a benign lesion such as a pulmonary hamartoma is a consideration. Could consider short-term follow-up diagnostic CT chest in 3-6 months to assess for interval change. [2] No evidence of suspected FDG avid local nodal mediastinal/hilar or distant metastatic disease. [3] Mildly lobulated nodular soft tissue in the subareolar right breast, without significant FDG avidity. Could correlate with prior mammography, if available. If not, screening mammography is recommended.	Aortic aneurysm pulmonary nodule PET/CT

Sample Case

Original Clinical Impression	LLM Impression (Flan-T5-XL, LORA finetuning)
[1] FDG PET/CT demonstrates short-term stability of the solitary nodule within the right upper lobe, which has only minimal associated FDG uptake, not elevated above mediastinal blood pool. Given the lack of significant FDG avidity, and the suggestion of macroscopic fat within the nodule on prior diagnostic chest CT, a benign lesion such as a pulmonary hamartoma is a consideration. Could consider short-term follow-up diagnostic CT chest in 3-6 months to assess for interval change. [2] No evidence of suspected FDG avid local nodal mediastinal/hilar or distant metastatic disease. [3] Mildly lobulated nodular soft tissue in the subareolar right breast, without significant FDG avidity. Could correlate with prior mammography, if available. If not, screening mammography is recommended.	[1] FDG PET/CT demonstrates a mildly FDG avid 1.2 x 1.3 cm subpleural nodule within the anteroinferior right upper lobe immediately superior to the right minor fissure, which is unchanged in size compared to [DATE]. This is nonspecific by PET criteria for an inflammatory/infectious etiology versus low-grade malignancy. Recommend close thoracic CT follow-up and consider tissue sampling for further evaluation. [2] No evidence of other sites of FDG-avid pulmonary or mediastinal/hilar metastatic disease. [3] Redemonstration of mildly lobulated nodular area of soft tissue within the subareolar right breast. This does not appear to have associated FDG uptake. This may represent a benign breast lesion such as adenoma or fibrocystic breast tissue. Consider correlation with mammogram and/or ultrasound as clinically indicated.

Summary

- LoRA achieved the best performance among the PEFT techniques we investigated
  - LoRA > IA3 > Prompt tuning
- PEFT has not reached the performance of full fine-tuning
- Limitations
  - Not match the trainable parameters
  - Not tune the hyperparameters to optimize the performance

Thank you

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