CS 4803 / 7643: Deep Learning

Topics:
- Recurrent Neural Networks (RNNs)
- BackProp Through Time (BPTT)

Zsolt Kira
Georgia Tech
Plan for Today

• Model
  – Recurrent Neural Networks (RNNs)

• Learning
  – BackProp Through Time (BPTT)
New Topic: RNNs
New Words

• Recurrent Neural Networks (RNNs)

• Recursive Neural Networks
  – General family; think graphs instead of chains

• Types:
  – “Vanilla” RNNs (Elman Networks)
  – Long Short Term Memory (LSTMs)
  – Gated Recurrent Units (GRUs)
  – ...

• Algorithms
  – BackProp Through Time (BPTT)
  – BackProp Through Structure (BPTS)
What’s wrong with MLPs?

- Problem 1: Can’t model sequences
  - Fixed-sized Inputs & Outputs
  - No temporal structure
What’s wrong with MLPs?

• Problem 1: Can’t model sequences
  – Fixed-sized Inputs & Outputs
  – No temporal structure

• Problem 2: Pure feed-forward processing
  – No “memory”, no feedback

Image Credit: Alex Graves, book
Why model sequences?

Figure Credit: Carlos Guestrin
Why model sequences?
Sequences are everywhere…

FOREIGN MINISTER.

THE SOUND OF

\[ x = \text{bringen sie bitte das auto zurück} \]
\[ y = \text{please return the car} \]
Even where you might not expect a sequence...

A group of people shopping at an outdoor market.
There are many vegetables at the fruit stand.

John has a dog. → S
NP → (S (NP NNP )NP (VP VBZ (NP DT NN )NP )VP . )S
Even where you might not expect a sequence…

Classify images by taking a series of “glimpses”
Even where you might not expect a sequence...

- Output ordering = sequence
Sequences in Input or Output?

• It’s a spectrum…

one to one

Input: No sequence
Output: No sequence
Example: "standard" classification / regression problems

Image Credit: Andrej Karpathy
Sequences in Input or Output?

• It’s a spectrum…

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
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<tbody>
<tr>
<td>No sequence</td>
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</table>

Example:
- "standard" classification / regression problems
- Im2Caption

Image Credit: Andrej Karpathy
Sequences in Input or Output?

• It’s a spectrum…

one to one

Input: No sequence
Output: No sequence
Example: “standard” classification / regression problems

one to many

Input: No sequence
Output: Sequence
Example: Im2Caption

many to one

Input: Sequence
Output: No sequence
Example: sentence classification, multiple-choice question answering

(C) Dhruv Batra and Zsolt Kira

Image Credit: Andrej Karpathy
Sequences in Input or Output?

• It’s a spectrum…

Input: No sequence
Output: No sequence
Example: "standard" classification / regression problems

Input: No sequence
Output: Sequence
Example: Im2Caption

Input: Sequence
Output: No sequence
Example: sentence classification, multiple-choice question answering

Input: Sequence
Output: Sequence
Example: machine translation, video classification, video captioning, open-ended question answering
2 Key Ideas

• Parameter Sharing
  – in computation graphs = adding gradients
Gradients add at branches

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
2 Key Ideas

- Parameter Sharing
  - in computation graphs = adding gradients

- “Unrolling”
  - in computation graphs with parameter sharing
How do we model sequences?

- No input

\[ s_t = f_\theta(s_{t-1}) \]
How do we model sequences?

- No input

\[ s_t = f_\theta(s_{t-1}) \]
How do we model sequences?

- With inputs

\[ s_t = f_{\theta}(s_{t-1}, x_t) \]
2 Key Ideas

• Parameter Sharing
  – in computation graphs = adding gradients

• “Unrolling”
  – in computation graphs with parameter sharing

• Parameter sharing + Unrolling
  – Allows modeling arbitrary sequence lengths!
  – Keeps numbers of parameters in check
Recurrent Neural Network

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
Recurrent Neural Network

usually want to predict a vector at some time steps

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
We can process a sequence of vectors $x$ by applying a **recurrence formula** at every time step:

$$h_t = f_W(h_{t-1}, x_t)$$

new state $\quad$ old state $\quad$ input vector at some time step

some function with parameters $W$
Recurrent Neural Network

We can process a sequence of vectors $\mathbf{x}$ by applying a recurrence formula at every time step:

$$h_t = f_W(h_{t-1}, x_t)$$

Notice: the same function and the same set of parameters are used at every time step.
(Vanilla) Recurrent Neural Network

The state consists of a single "hidden" vector $h$:

$$y_t = W_{hy}h_t + b_y$$

$$h_t = f_W(h_{t-1}, x_t)$$

$$h_t = \tanh(W_{hh}h_{t-1} + W_{xh}x_t + b_h)$$

Sometimes called a “Vanilla RNN” or an “Elman RNN” after Prof. Jeffrey Elman

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph
RNN: Computational Graph

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph

Re-use the same weight matrix at every time-step

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph: Many to Many

\[ x_1, x_2, x_3 \rightarrow h_0, h_1, h_2, h_3, \ldots, h_T \rightarrow y_1, y_2, y_3, y_T \]

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph: Many to Many

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph: Many to Many

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
RNN: Computational Graph: Many to One
RNN: Computational Graph: One to Many

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
Sequence to Sequence: Many-to-one + one-to-many

**Many to one:** Encode input sequence in a single vector

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
Sequence to Sequence: Many-to-one + one-to-many

**Many to one**: Encode input sequence in a single vector

**One to many**: Produce output sequence from single input vector
Example:
Character-level Language Model

Vocabulary:
[h,e,l,o]

Example training sequence:
“hello”
Example:
Character-level Language Model

Vocabulary: [h,e,l,o]

Example training sequence: “hello”
Distributed Representations Toy Example

- Local vs Distributed

(a)

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<thead>
<tr>
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Distributed Representations Toy Example

- Can we interpret each dimension?
Power of distributed representations!

Local: \[ \bullet \bullet \circ \bullet = VR + HR + HE = ? \]

Distributed: \[ \bullet \bullet \circ \bullet = V + H + E \approx \bigcirc \]
Example:
Character-level Language Model

Vocabulary: [h,e,l,o]

Example training sequence: “hello”
Training Time: MLE / “Teacher Forcing”

Example:
Character-level Language Model

Vocabulary: [h,e,l,o]

Example training sequence: “hello”
Test Time: Sample / Argmax

Example:
Character-level Language Model Sampling

Vocabulary: [h,e,l,o]

At test-time sample characters one at a time, feed back to model
Test Time: Sample / Argmax

Example:
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At test-time sample characters one at a time, feed back to model
Backpropagation through time

Forward through entire sequence to compute loss, then backward through entire sequence to compute gradient.

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
**Truncated** Backpropagation through time

Run forward and backward through chunks of the sequence instead of whole sequence
**Truncated** Backpropagation through time

Carry hidden states forward in time forever, but only backpropagate for some smaller number of steps
**Truncated** Backpropagation through time
Deep (Stacked) RNNs

RNN:

$$h_t^l = \tanh W^l \left( \begin{array}{c} h_t^{l-1} \\ h_{t-1}^l \end{array} \right)$$

$$h \in \mathbb{R}^n, \quad W^l \in [n \times 2n]$$
```python
def sample(h, seed_ix, n):
    # sample a sequence of integers from the model
    s = memory_state, seed_ix = seed letter for first time step
    for t in range(n):
        x = np.zeros(vocab_size, 1)
        p = np.exp(pij) / np.sum(np.exp(pij))
        i = np.random.choice(vocab_size, 1, p=p)
        x[i] = 1
        seed_ix = i
    return x

# sample from the model, new and then
if m == 0:
    for i in range(200):
        sample = sample(h, seed_ix, 20)
        print('


')
```
THE SONNETS

by William Shakespeare

From fairest creatures we desire increase,
That thereby beauty's rose might never die,
But as the riper should by time decease,
His tender heir might bear his memory:
But thou, contracted to thine own bright eyes,
Feed'st thy light's flame with self-substantial fuel,
Making a famine where abundance lies,
Thyself thy foe, to thy sweet self too cruel:
Thou art now the world's fresh ornament,
And only herald to the gaudy spring,
Within thine own bud buried thy content,
And tender churl mak'st waste in riddling:
Ply the world, or else this gluton be,
To eat the world's due, by the grave and thee.

When forty winters shall besiege thy brow,
And dig deep trenches in thy beauty's field,
Thy youth's proud livery so gazed on now,
Will be a tattered weed of small worth held;
Then being asked, where all thy beauty lies,
Where all the treasure of thy lusty days;
To say, within thine own deep sunken eyes,
Were an all-eating shame, and thriftless praise.
How much more praise deserv'd thy beauty's use,
If thou couldst answer 'This fair child of mine
Shall sum my cost, and make my old excuse,'
Proving his beauty by succession thine!
This were to be new made when thou art old,
And see thy blood warm when thou feel'st it cold.
train more

"Tmont thithey" fomesscerliund
Keushey. Thom here
sheulke, amerenith ol sivh I lalterthend Bleipile shuwy fil on aseterlome
coanigenncc Phe lism thond hon at. MeiDimorotion in ther thize."

train more

Aftair fall unsuch that the hall for Prince Velzonski's that me of
her hearly, and behs to so arwage fiving were to it beloge, pawu say falling misfort
how, and Gognition is so overelical and ofter.

train more

"Why do what that day," replied Natasha, and wishing to himself the fact the
princess, Princess Mary was easier, fed in had oftened him.
Pierre aking his soul came to the packs and drove up his father-in-law women.
PANDARUS:
Alas, I think he shall be come approached and the day
When little strain would be attain'd into being never fed,
And who is but a chain and subjects of his death,
I should not sleep.

Second Senator:
They are away this miseries, produced upon my soul,
Breaking and strongly should be buried, when I perish
The earth and thoughts of many states.

DUKE VINCENTIO:
Well, your wit is in the care of side and that.

Second Lord:
They would be ruled after this chamber, and
my fair nues begun out of the fact, to be conveyed,
Whose noble souls I'll have the heart of the wars.

Clown:
Come, sir, I will make did behold your worship.

VIOLA:
I’ll drink it.

VIOLA:
Why, Salisbury must find his flesh and thought
That which I am not aps, not a man and in fire,
To show the reining of the raven and the wars
To grace my hand reproach within, and not a fair are hand,
That Caesar and my goodly father's world;
When I was heaven of presence and our fleets,
We spare with hours, but cut thy council I am great,
Murdered and by thy master's ready there
My power to give thee but so much as hell:
Some service in the noble bondman here,
Would show him to her wine.

KING LEAR:
0, if you were a feeble sight, the courtesy of your law,
Your sight and several breath, will wear the gods
With his heads, and my hands are wonder'd at the deeds,
So drop upon your lordship's head, and your opinion
Shall be against your honour.
The Stacks Project: open source algebraic geometry textbook

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
For $\bigoplus_{m=1}^{n} \mathcal{L}_{P_{m}}$, where $\mathcal{L}_{P_{m}} = 0$, hence we can find a closed subset $\mathcal{H}$ in $\mathcal{H}$ and any sets $\mathcal{F}$ on $X$, $U$ is a closed immersion of $S$, then $U \to T$ is a separated algebraic space.

Proof of (1). It also start we get

$$S = \text{Spec}(R) = U \times_X U \times_X U$$

and the corresponding in the fibre product covering we have to prove the lemma generated by $\prod Z \times_U U \to V$. Consider the maps $M$ along the set of points $\text{Sch}_{fpf}$ and $U \to U$ is the fibre category of $S$ in $U$ in Section, ?? and the fact that any $U$ affine, see Morphisms, Lemma ???. Hence we obtain a scheme $S$ and any open subset $W \subset U$ in $\mathcal{Sh}(G)$ such that $\text{Spec}(R') \to S$ is smooth or an

$$U = \bigcup U_i \times_S U_i$$

which has a nonzero morphism we may assume that $f_i$ is of finite presentation over $S$. We claim that $\mathcal{O}_{X,x}$ is a scheme where $x,x',x'' \in S'$ such that $\mathcal{O}_{X,x'} \to \mathcal{O}_{X,x''}$ is separated. By Algebra, Lemma ?? we can define a map of complexes $GL_{S'}(x' / S'')$ and we win.

To prove study we see that $\mathcal{F}|_{U}$ is a covering of $X'$, and $\mathcal{F}_i$ is an object of $\mathcal{F}_{X/S}$ for $i > 0$ and $\mathcal{F}_e$ exists and let $\mathcal{F}_e$ be a presheaf of $\mathcal{O}_X$-modules on $\mathcal{C}$ as a $\mathcal{F}$-module. In particular $\mathcal{F} = U/\mathcal{F}$ we have to show that

$$\overline{M}^* = \mathcal{F} \otimes_{\text{Spec}(S)} \mathcal{O}_{S,S} / i_{x}^{-1} \mathcal{F}$$

is a unique morphism of algebraic stacks. Note that

$$\text{Arrows} = \text{Sch}(S)_{fpf} \times_{\text{Spec}(S)} \text{Sch}(S)_{fpf}$$

and

$$V = \Gamma(S, O) \to (U, \text{Spec}(A))$$

is an open subset of $X$. Thus $U$ is affine. This is a continuous map of $X$ is the inverse, the groupoid scheme $S$.

Proof. See discussion of sheaves of sets.

The result for prove any open covering follows from the less of Example ???. It may replace $S$ by $X_{spaces,etale}$ which gives an open subspace of $X$ and $T$ equal to $Z_{zar}$, see Descent, Lemma ???. Namely, by Lemma ?? we see that $R$ is geometrically regular over $S$.

Lemma 0.1. Assume (3) and (3) by the construction in the description.

Suppose $X = \lim X$ (by the formal open covering $X$ and a single map $\text{Proj}_X(A) = \text{Spec}(B)$ over $U$ compatible with the complex $\text{Set}(A) = \Gamma(X, \mathcal{O}_X, \mathcal{C})$).

When in case co of to show that $\mathcal{Q} \to \mathcal{C}_{X/U}$ is stable under the following result in the second conditions of (1), and (3). This finishes the proof. By Definition ?? (without element is when the closed subschemes are catenary. If $T$ is surjective we may assume that $T$ is connected with residue fields of $S$. Moreover there exists a closed subspace $Z \subset X$ of $X$ where $U$ in $X'$ is proper (some defining as a closed subset of the uniqueness it suffices to check the fact that the following theorem)

(1) $f$ is locally of finite type. Since $S = \text{Spec}(R)$ and $Y = \text{Spec}(R)$.

Proof. This is form all sheaves of sheaves on $X$. But given a scheme $U$ and a surjective étale morphism $U \to X$. Let $U \cap U' \to \lim U_i$ be the scheme $X$ over $S$ at the schemes $X_i \to X$ and $U = \lim X_i$.

The following lemma surjective rest-recompose of the implies that $\mathcal{F}_{x_0} = \mathcal{F}_{x_0} = \mathcal{F}_{x_i \to 0}$.

Lemma 0.2. Let $X$ be a locally Noetherian scheme over $S$, $E = \mathcal{F}_{X/S}$. Set $I = \mathcal{J}_1 \subset T_n$. Since $T_n \subset T_n$ are nonzero over $i \leq p$ is a subset of $\mathcal{J}_{n,0} \to \mathcal{A}_n$ works.

Lemma 0.3. In Situation ???. Hence we may assume $q' = 0$.

Proof. We will use the property we see that $p$ is the next functor (??). On the other hand, by Lemma ?? we see that $\mathcal{J} = \mathcal{O}_X(D)$ where $K$ is an $F$-algebra where $\delta_{n+1}$ is a scheme over $S$. 


Proof. Omitted.

**Lemma 0.1.** Let $C$ be a set of the construction.

Let $C$ be a gerber covering. Let $F$ be a quasi-coherent sheaves of $O$-modules. We have to show that

$$O_{O_X} = O_X(L)$$

Proof. This is an algebraic space with the composition of sheaves $F$ on $X_{etale}$ we have

$$O_X(F) = \{\text{morph} \times O_X (G, F)\}$$

where $G$ defines an isomorphism $F \to F$ of $O$-modules.

**Lemma 0.2.** This is an integer $Z$ is injective.

Proof. See Spaces, Lemma ??.

**Lemma 0.3.** Let $S$ be a scheme. Let $X$ be a scheme and $X$ is an affine open covering. Let $U \subset X$ be a canonical and locally of finite type. Let $X$ be a scheme. Let $X$ be a scheme which is equal to the formal complex.

The following to the construction of the lemma follows.

Let $X$ be a scheme. Let $X$ be a scheme covering. Let

$$b : X \to Y' \to Y \to Y' \times_X Y \to X.$$

be a morphism of algebraic spaces over $S$ and $Y$.

Proof. Let $X$ be a nonzero scheme of $X$. Let $X$ be an algebraic space. Let $F$ be a quasi-coherent sheaf of $O_X$-modules. The following are equivalent

1. $F$ is an algebraic space over $S$.
2. If $X$ is an affine open covering.

Consider a common structure on $X$ and $X$ the functor $O_X(U)$ which is locally of finite type.

This since $F \in \mathcal{F}$ and $x \in \mathcal{G}$ the diagram

$$
\begin{array}{c}
S \\
\downarrow \\
\xi \\
\downarrow \\
O_Y \\
\downarrow \\
gor_\alpha \\
\end{array}
$$

is a limit. Then $\mathcal{G}$ is a finite type and assume $S$ is a flat and $F$ and $\mathcal{G}$ is a finite type $f$. This is of finite type diagrams, and

- the composition of $\mathcal{G}$ is a regular sequence,
- $O_X$ is a sheaf of rings.

Proof. We have seen that $X = \text{Spec}(R)$ and $F$ is a finite type representable by algebraic space. The property $F$ is a finite morphism of algebraic stacks. Then the cohomology of $X$ is an open neighbourhood of $U$.

Proof. This is clear that $\mathcal{G}$ is a finite presentation, see Lemmas ??.

A reduced above we conclude that $U$ is an open covering of $C$. The functor $F$ is a "field"

$$O_{X,z} \to \mathcal{F} \to \mathcal{O}_{X,z} \to \mathcal{O}_{X,z}(O_{X,z})$$

is an isomorphism of covering of $O_X$. If $F$ is the unique element of $\mathcal{F}$ such that $X$ is an isomorphism.

The property $F$ is a disjoint union of Proposition ?? and we can filtered set of presentations of a scheme $O_X$-algebra with $F$ are opens of finite type over $S$.

If $\mathcal{F}$ is a scheme theoretic image points.

If $F$ is a finite direct sum $O_{X,z}$ is a closed immersion, see Lemma ??.

This is a sequence of $F$ is a similar morphism.
Linux kernel source tree

- **520,037** commits
- **1** branch
- **420** releases
- **5,039** contributors

**Branch:** master - linux / +

**Merge branch 'drm-fixes' of git://people.freedesktop.org/~airlied/linux**

- **torvalds** authored 9 hours ago

- **Documentation**
- Merge git://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/... 6 days ago
- **arch**
- Merge branch 'x86-urgent-for-linus' of git://git.kernel.org/pub/scm/li... a day ago
- **block**
- block: discard bdi_unregister() in favour of bdi_destroy() 9 days ago
- **crypto**
- Merge branch 'drm-fixes' of git://people.freedesktop.org/~airlied/linux 10 days ago
- **drivers**
- Merge branch 'drm-fixes' of git://people.freedesktop.org/~airlied/linux 9 hours ago
- **firmware**
- firmware/hex2tw.c: restore missing default in switch statement 2 months ago
- **fs**
- vfs: read_file_handle only once in handle_to_path 4 days ago
- **include**
- Merge branch 'perf-urgent-for-linus' of git://git.kernel.org/pub/scm/... a day ago
- **init**
- init: fix regression by supporting devices with major:minor:offset fo... a month ago
- **io**
- Merge branch 'for-linus' of git://git.kernel.org/pub/scm/linux/kernel... 3 months ago

**Latest commit:** 4b1706927d

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**Clone in Desktop**

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Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
static void do_command(struct seq_file *m, void *v)
{
    int column = 32 << (cmd[2] & 0x80);
    if (state)
        cmd = (int)(int_state ^ (in_8(&ch->ch_flags) & Cmd) ? 2 : 1);
    else
        seq = 1;
    for (i = 0; i < 16; i++) {
        if (x & (1 << i))
            pipe = (in_use & UMXTHREAD_UNCCA) +
                ((count & 0x00000000ffffffff) & 0x0000000f) << 8;
        if (count == 0)
            sub(pid, ppc_md.kexec_handle, 0x20000000);
        pipe_set_bytes(i, 0);
    }
    /* Free our user pages pointer to place camera if all dash */
    subsystem_info = &of_changes[PAGE_SIZE];
    rek_controls(offset, idx, &soffset);
    /* Now we want to deliberately put it to device */
    control_check_polarity(&context, val, 0);
    for (i = 0; i < COUNTER; i++)
        seq_puts(s, "policy ");
}
/*
 * Copyright (c) 2006-2010, Intel Mobile Communications. All rights reserved.
 *
 * This program is free software; you can redistribute it and/or modify it
 * under the terms of the GNU General Public License version 2 as published by
 * the Free Software Foundation.
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
 *
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software Foundation,
 * Inc., 675 Mass Ave, Cambridge, MA 02139, USA.
 */

#include <linux/kexec.h>
#include <linux/errno.h>
#include <linux/io.h>
#include <linux/platform_device.h>
#include <linux/multi.h>
#include <linux/cr/event.h>

#include <asm/io.h>
#include <asm/prom.h>
#include <asm/e820.h>
#include <asm/system_info.h>
#include <asm/setew.h>
#include <asm/pgproto.h>
```c
#include <asm/io.h>
#include <asm/prom.h>
#include <asm/e820.h>
#include <asm/system_info.h>
#include <asm/setsid.h>
#include <asm/pgproto.h>

#define REG_PG     vesa_slot_addr_pack
#define PFM_NOCOMP AF8R(0, load)
#define STACK_DDR(type)    (func)

#define SWAP_ALLOCATE(nr)  (e)
#define emulate_sigs()     arch_get_unaligned_child()
#define access_rw(TST)     asm volatile("movd %esp, %0, %3" : : "r" (0));
                       
if (__type & DO_READ)
    static void stat_PC_SEC __read_mostly offsetf(struct seq_argsqueue, \
                       pC>[1]);

static void os_prefix(unsigned long sys)
{
    #ifdef CONFIG_PREEMPT
        PUT_PARAM_RAID(2, sel) = get_state_state();
        set_pid_sum((unsigned long)state, current_state_str(),
                   (unsigned long)-1->lr_full; low;
    }
```
Searching for interpretable cells
Searching for interpretable cells

/* Unpack a filter field's string representation from user-space */
char *audit_unpack_string(void **bufp, size_t *remain, size_t len)
{
    char *str;
    if (!*bufp || (len == 0) || (len > *remain))
        return ERR_PTR(-EINVAL);
    /* Of the currently implemented string fields, PATH_MAX defines the longest valid length. */
Searching for interpretable cells

"You mean to imply that I have nothing to eat out of.... On the contrary, I can supply you with everything even if you want to give dinner parties," warmly replied Chichagov, who tried by every word he spoke to prove his own rectitude and therefore imagined Kutuzov to be animated by the same desire.

Kutuzov, shrugging his shoulders, replied with his subtle penetrating smile: "I meant merely to say what I said."

quote detection cell

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Searching for interpretable cells

Cell sensitive to position in line:

The sole importance of the crossing of the Berezina lies in the fact that it plainly and indubitably proved the fallacy of all the plans for cutting off the enemy's retreat and the soundness of the only possible line of action—the one Kutuzov and the general mass of the army demanded—namely, simply to follow the enemy up. The French crowd fled at a continually increasing speed and all its energy was directed to reaching its goal. It fled like a wounded animal and it was impossible to block its path. This was shown not so much by the arrangements it made for crossing as by what took place at the bridges. When the bridges broke down, unarmed soldiers, people from Moscow and women with children who were with the French transport, all—carried on by vis inertiae—pressed forward into boats and into the ice-covered water and did not, surrender.

line length tracking cell

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Searching for interpretable cells

```
/* Duplicate LSM field information. The lsm_rule is opaque, so
 * re-initialized. */
static inline int audit_dupe_lsm_field(struct audit_field *df,
     struct audit_field *sf)
{
    int ret = 0;
    char *lsm_str;
    /* our own copy of lsm_str */
    lsm_str = kstrdup((sf->lsm_str, GFP_KERNEL);
    if (unlikely(!_lsm_str))
        return -ENOMEM;
    df->lsm_str = lsm_str;
    /* our own (refreshed) copy of lsm_rule */
    ret = security_audit_rule_init(df->type, df->op, df->lsm_str,
        (void *)&df->lsm_rule);
    /* keep currently invalid fields around in case they
     * become valid after a policy reload. */
    if (ret == -EINVAL) {
        pr_warn("audit rule for LSM \%s\ is invalid\n",
            df->lsm_str);
        ret = 0;
    }
    return ret;
}
```

quote/comment cell

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Searching for interpretable cells

```c
#ifdef CONFIG_AUDITSYSCALL
static inline int audit_match_class_bits(int class, u32 *mask)
{
    int i;
    if (classes[class]) {
        for (i = 0; i < AUDIT_BITMASK_SIZE; i++)
            if (mask[i] & classes[class][i])
                return 0;
    }
    return 1;
}
#endif
```

code depth cell
Neural Image Captioning

Image Embedding (VGGNet)

Convolution Layer + Non-Linearity
Pooling Layer
Convolution Layer + Non-Linearity
Pooling Layer
Fully-Connected MLP

4096-dim
Neural Image Captioning

Image Embedding (VGGNet)

Convolution Layer + Non-Linearity

Pooling Layer

Convolution Layer + Non-Linearity

Pooling Layer

Fully-Connected MLP

4096-dim
Neural Image Captioning

\[
\text{Image Embedding (VGGNet)} \rightarrow \text{Linear} \rightarrow \text{RNN} \rightarrow \text{RNN} \rightarrow \text{RNN} \rightarrow \text{RNN} \rightarrow \text{RNN} \\
\langle \text{start} \rangle \rightarrow \text{Two} \rightarrow \text{people} \rightarrow \text{and} \rightarrow \text{two} \rightarrow \text{horses.}
\]
Neural Image Captioning

- Linear
- RNN
- $y_1$
- $y_2$
- $y_3$
- $y_4$
- $y_5$

P(next)  P(next)  P(next)  P(next)  P(next)  P(next)

<start>  Two  people  and  two  horses.
“straw hat”

training example
“straw hat”
training example
“straw hat”

training example
before:
\[ h_0 = \max(0, W_{xh} \times x_0) \]

now:
\[ h_0 = \max(0, W_{xh} \times x_0 + W_{ih} \times v) \]
“straw hat” training example

Diagram showing a sequence of image classification layers: 
- Convolutional layers (conv-64, conv-128, conv-256, conv-512, conv-512, maxpool) 
- Fully connected layers (FC-4096, FC-4096, FC-1000) 
- Softmax layer

Sequence of nodes: 
- Initial node: <START>
- Intermediate nodes: straw, hat
- Final node: END
test image

sample!
test image

sample!
<END> token => finish.
test image

sample! 
<END> token => finish.

- Don’t have to do greedy word-by-word sampling, can also search over longer phrases with beam search
Beam Search

• Proceed from left to right
• Maintain N partial captions
• Expand each caption with possible next words
• Discard all but the top N new partial translations
Image Captioning: Example Results

A cat sitting on a suitcase on the floor

A cat is sitting on a tree branch

A dog is running in the grass with a frisbee

A white teddy bear sitting in the grass

Two people walking on the beach with surfboards

A tennis player in action on the court

Two giraffes standing in a grassy field

A man riding a dirt bike on a dirt track

Captions generated using neuraltalk2
All images are CC0 Public domain:
cat suitcase cat tree dog bear surfers tennis giraffe motorcycle

Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
Image Captioning: Failure Cases

A woman is holding a cat in her hand

A woman standing on a beach holding a surfboard

A person holding a computer mouse on a desk

A bird is perched on a tree branch

A man in a baseball uniform throwing a ball

Captions generated using neuraltalk2
All images are CC0 Public domain: fur coat, handstand, spider web, baseball

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Image Captioning with Attention

Image Captioning with Attention


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Image Captioning with Attention


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Image Captioning with Attention

- CNN
- Image: \( H \times W \times 3 \)
- Features: \( L \times D \)
- Distribution over \( L \) locations
- Distribution over vocab
- \( a_1 \)
- \( a_2 \)
- \( d_1 \)
- \( h_0 \) → \( h_1 \)
- Weighted combination of features
- \( z_1 \)
- Weighted features: \( D \)
- First word


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Image Captioning with Attention


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Image Captioning with Attention

Image Captioning with Attention

Soft attention

Hard attention

A bird flying over a body of water

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Slide Credit: Fei-Fei Li, Justin Johnson, Serena Yeung, CS 231n
Image Captioning with Attention

A woman is throwing a frisbee in a park.
A dog is standing on a hardwood floor.
A stop sign is on a road with a mountain in the background.
A little girl sitting on a bed with a teddy bear.
A group of people sitting on a boat in the water.
A giraffe standing in a forest with trees in the background.

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