Dynamic data structures – Linked lists

Basics of Programming 1

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Content

Chapter 1

Dynamic data structures

Dynamic data structure – motivation

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- We are writing a chess program, in which there is undo option for arbitrary number of moves.
- The undo-list is the log of the game, its elements are the moves.
  - Which piece
  - From where
  - Where to
  - Who is captured (removed)
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  - From where
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  - Who is captured (removed)
- For logging we use the memory we really need, no more.
- The final length of the log will be known only at the end of the game.
- We have to increase the amount of allocated memory with each step (or reduce it, if we undo a move).

Dyanmic data structure – motivation

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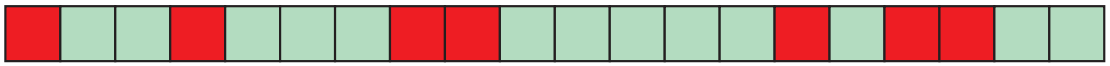

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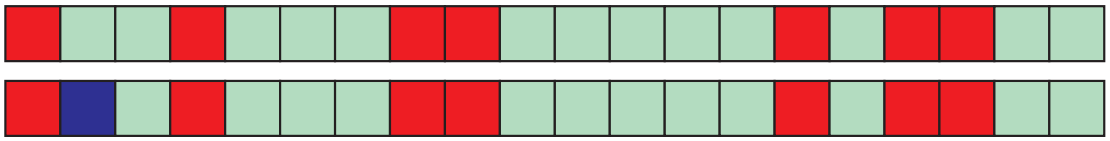

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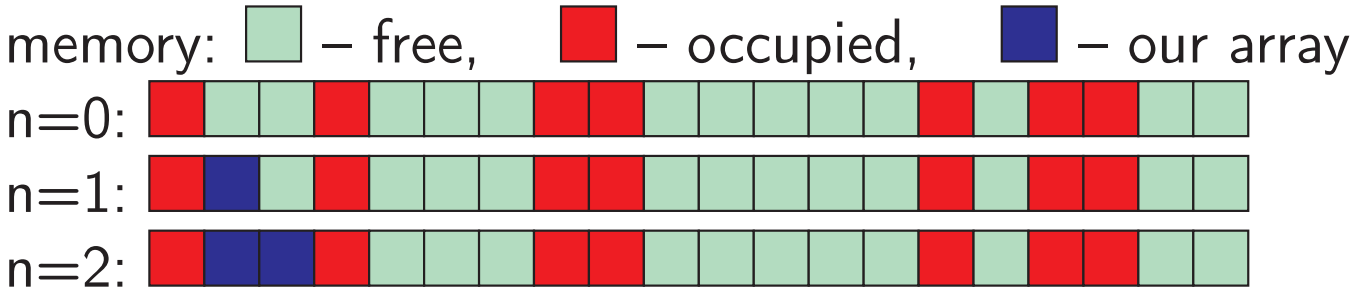

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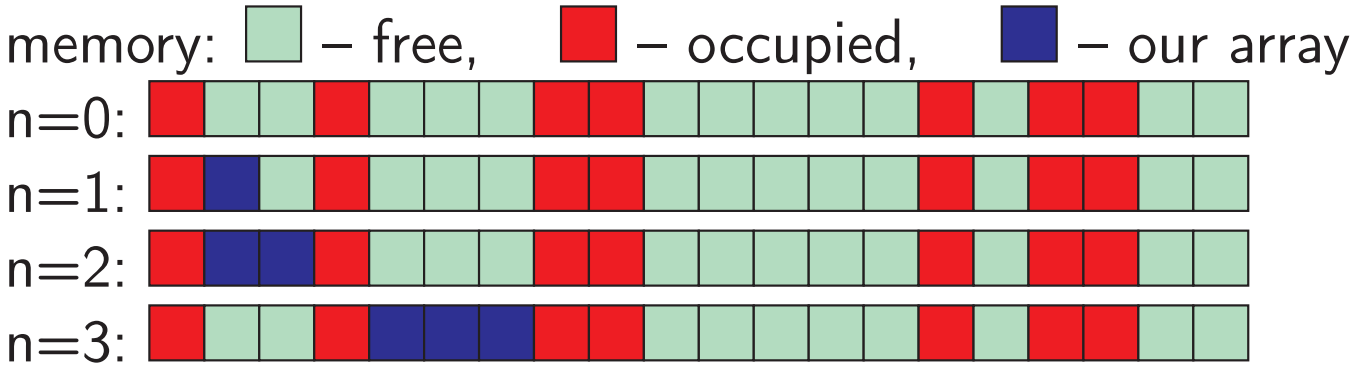

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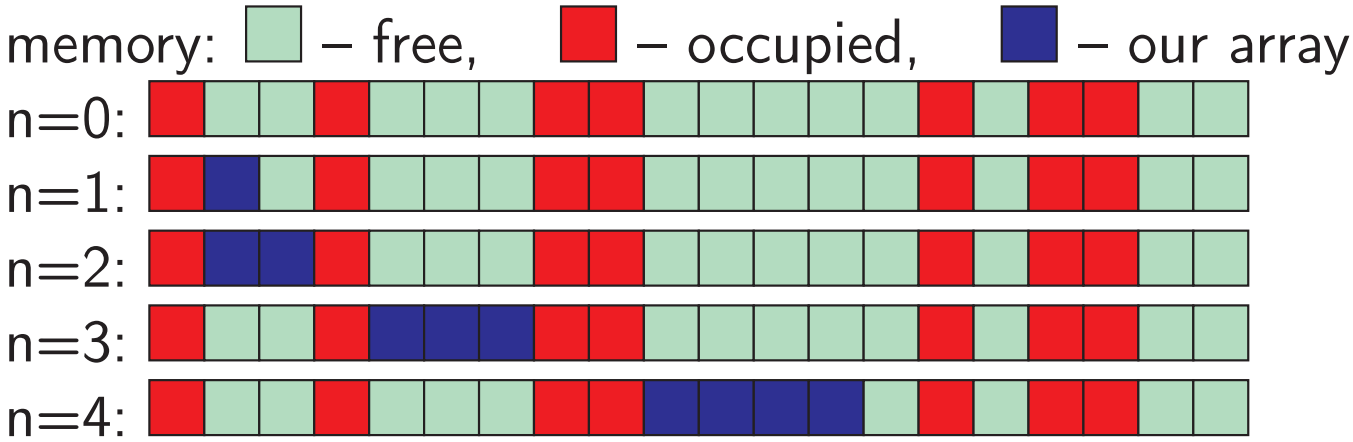

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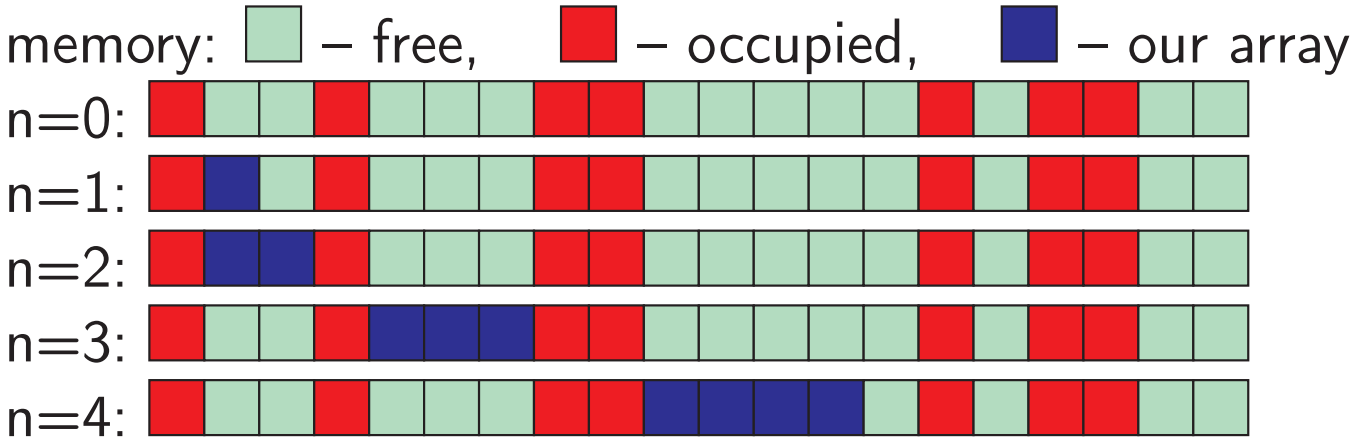

- We need a data structure that does not use continuous blocks of memory, and its strucure changes dynamically during the lifecycle of the program.

Dynamic data structure

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Dynamic data structure:

- its size or structure changes during the lifecycle of the program
- it is realized with self-referencing structure

Self-referencing structure

A compound data structure, that contains pointers pointing to itself

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- `next` points to a structure that is of the same type, as the one containing the pointer itself.
- `struct listelem` structure is renamed to `listelem`, but when declaring `next`, we must use the long name (because the compiler doesn't know, what nickname we will give to it).

Chapter 2

Singly linked lists

Linked list

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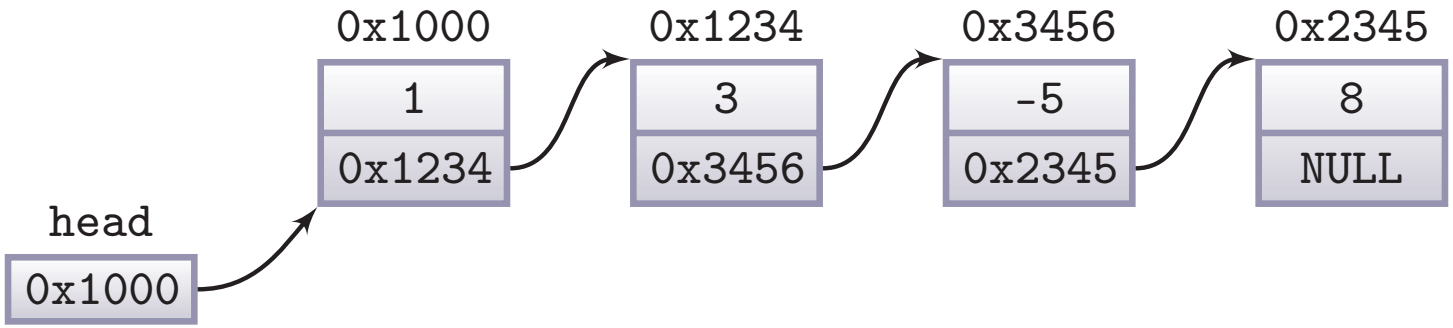

- List of `listelem` type variables
- Memory is allocated dynamically, separately for each element
- Elements do not form a continuous block in memory
- Each element contains the address of the next element
- The first element is defined by the `head` pointer
- The last element points to nowhere (`NULL`)

Linked list

- Empty list

Linked list

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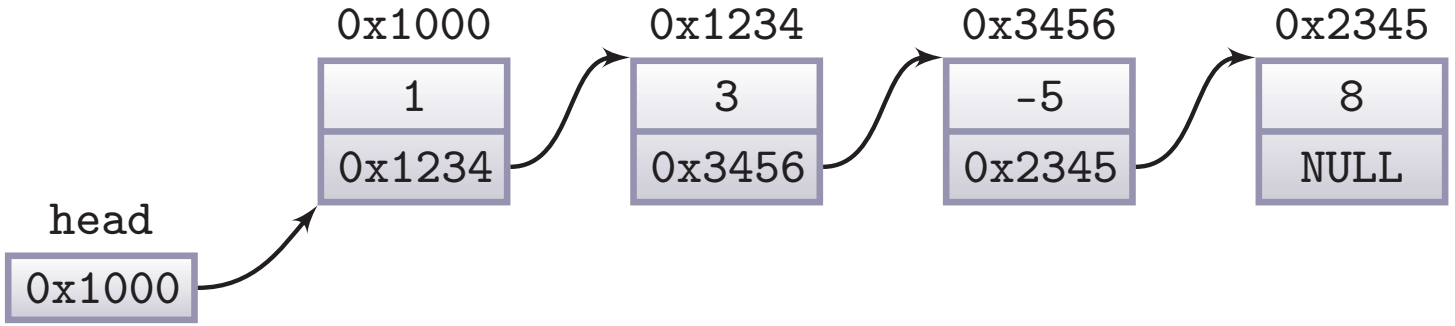
- List is a self-referencing (recursive) data structure. Each element points to a list.



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- The list
  - elements store the address of the next element, this may need a lot of memory
  - can make use of gaps in the fragmented memory
  - only the next element can be accessed immediately
  - inserting a new element involves only a little work

Traversing a list

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- For traversing we need an auxiliary pointer (p), that will run along the list.

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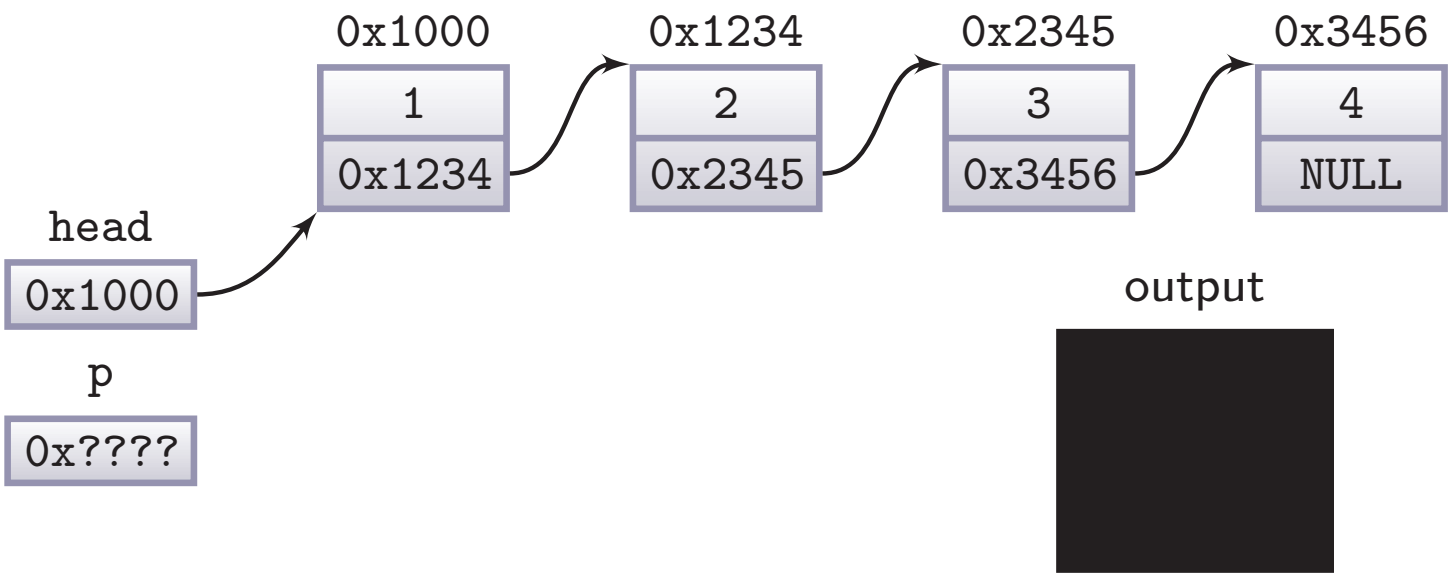

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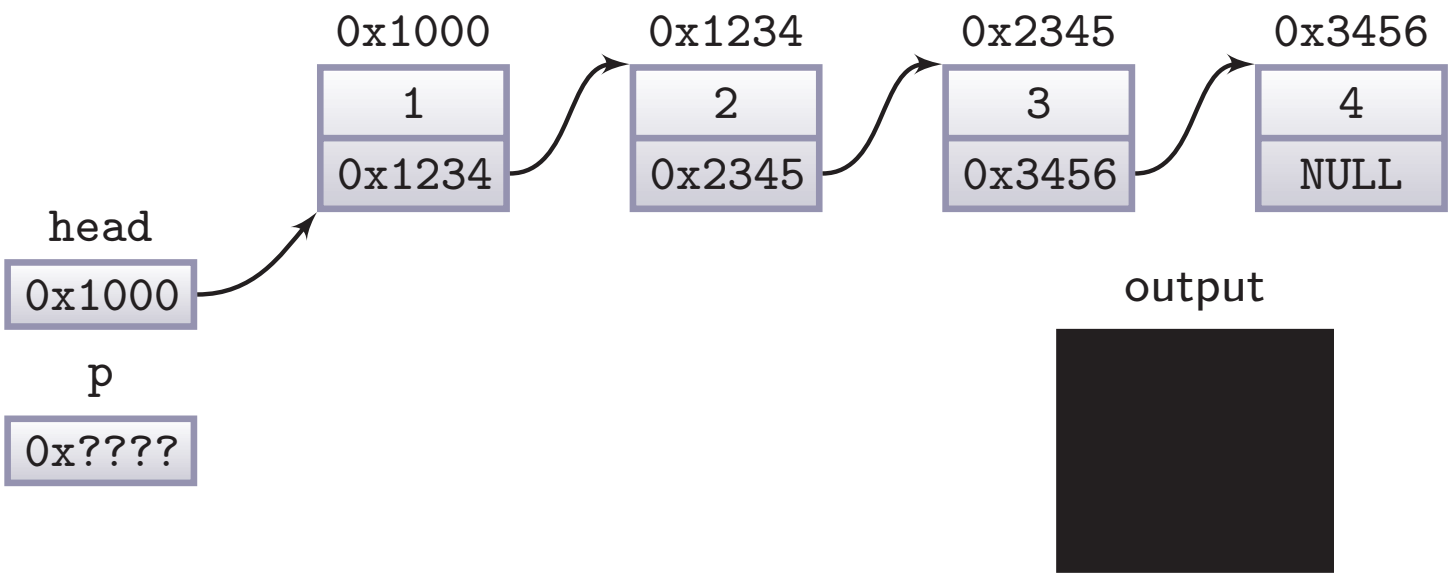

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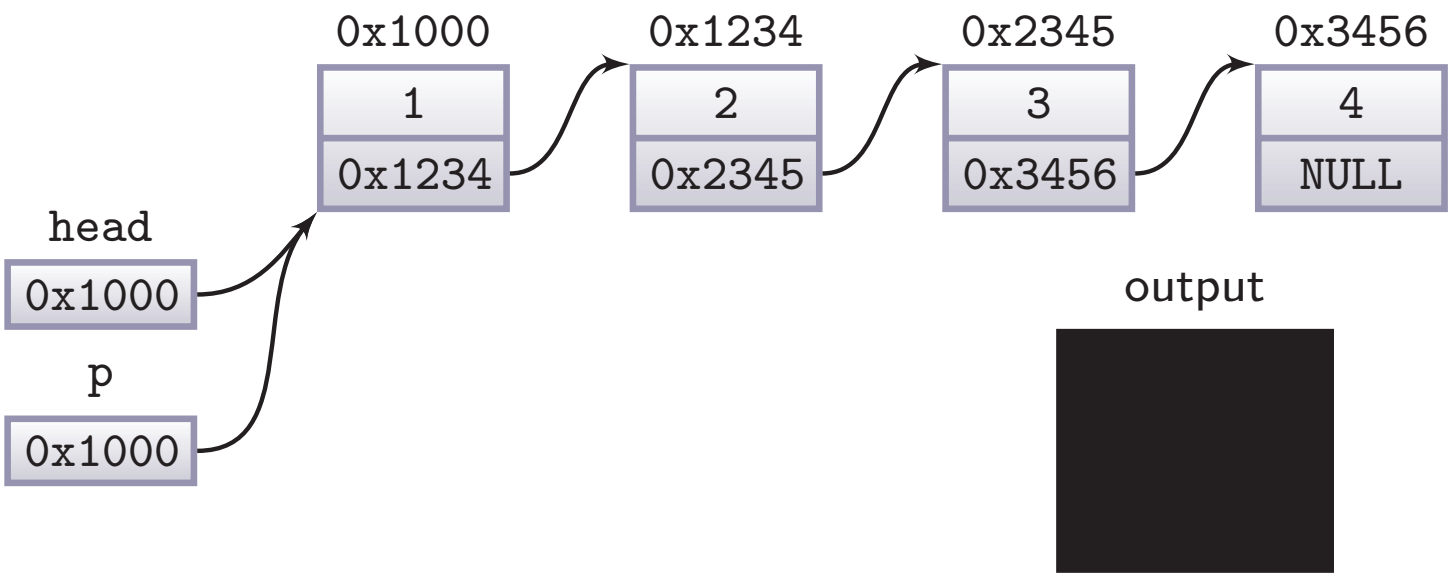

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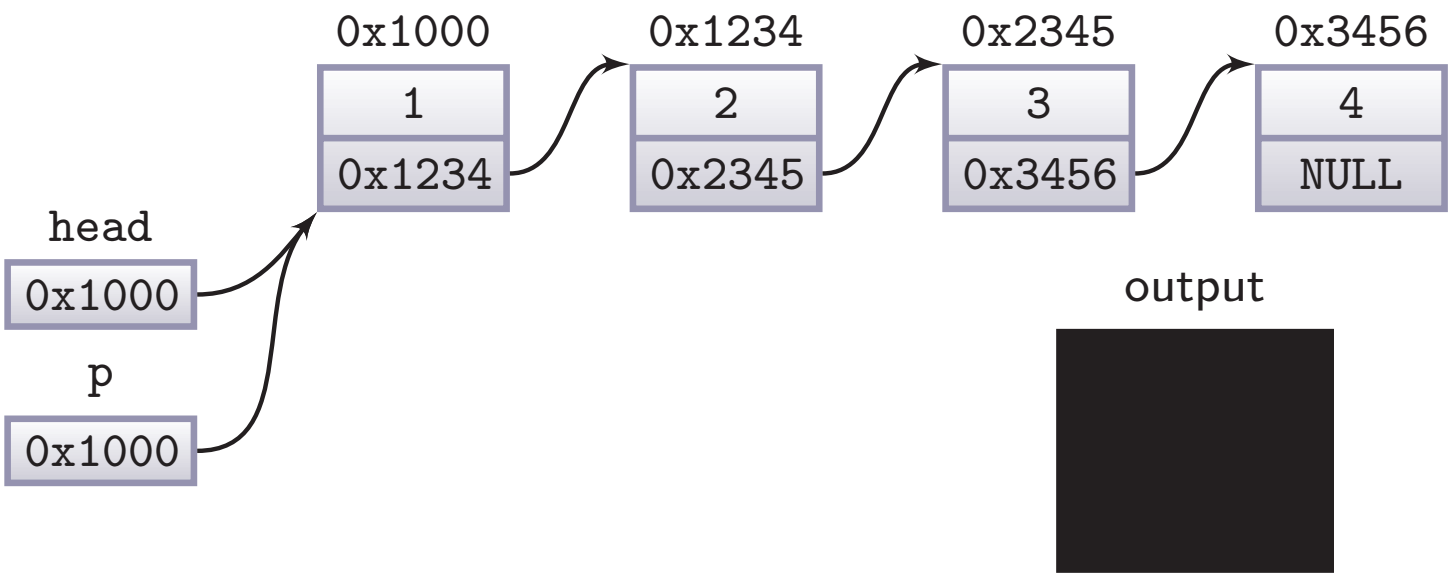

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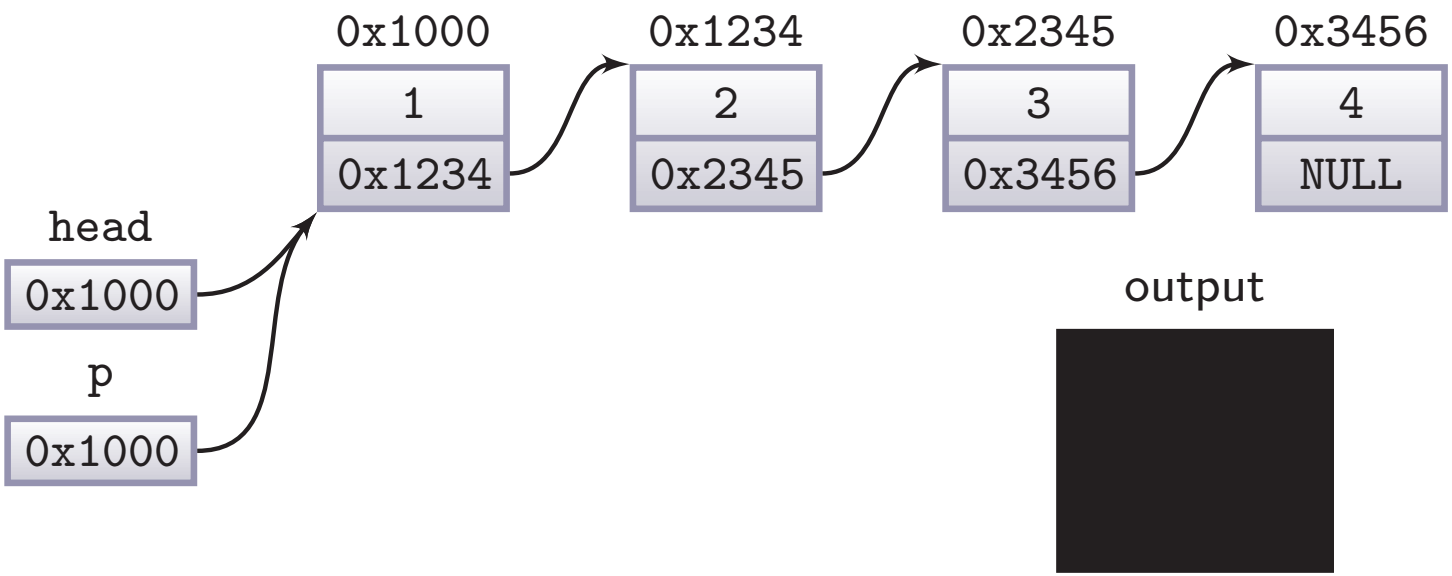

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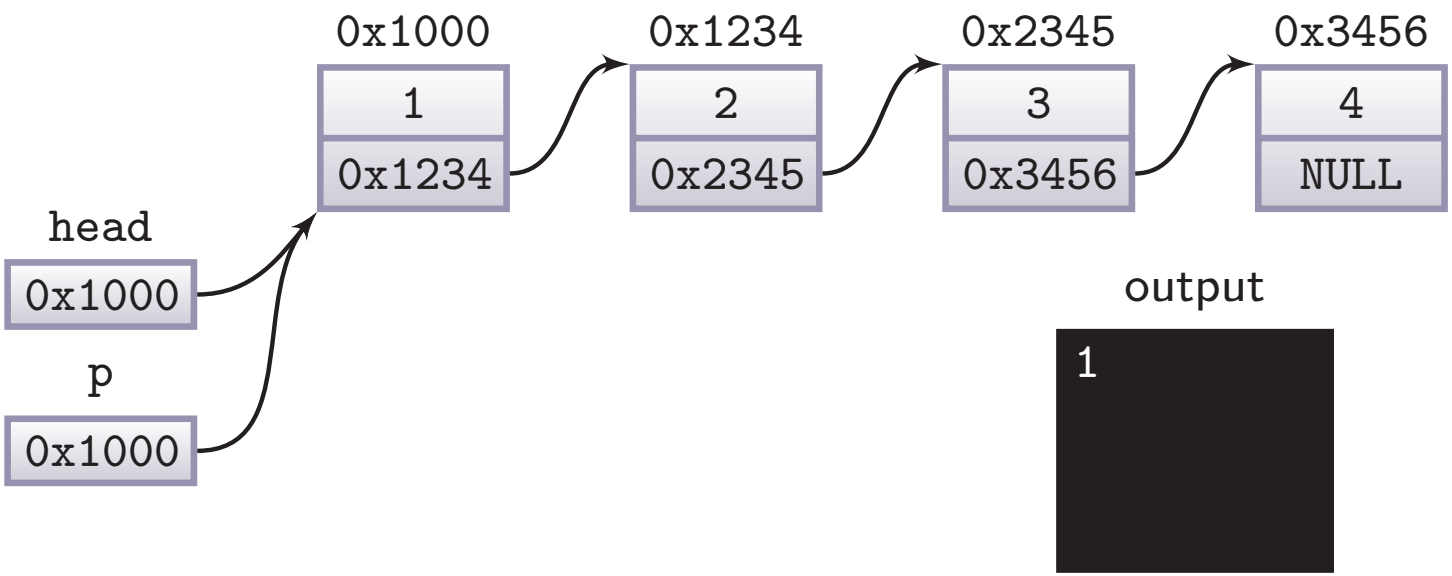

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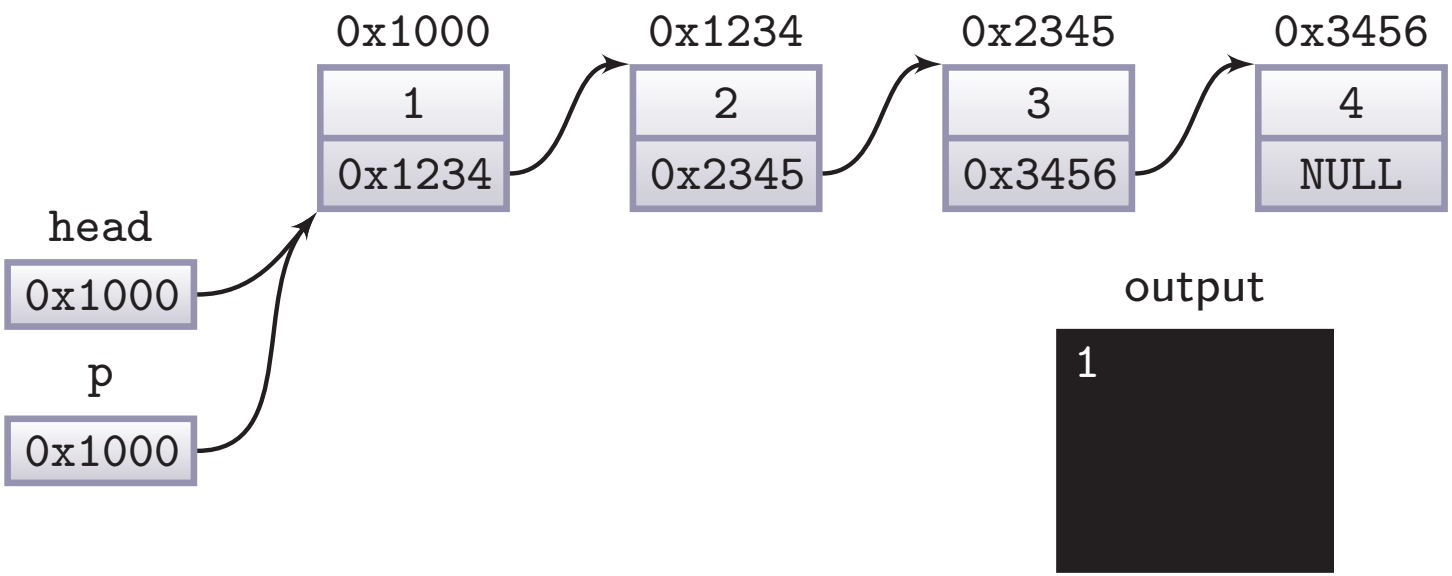

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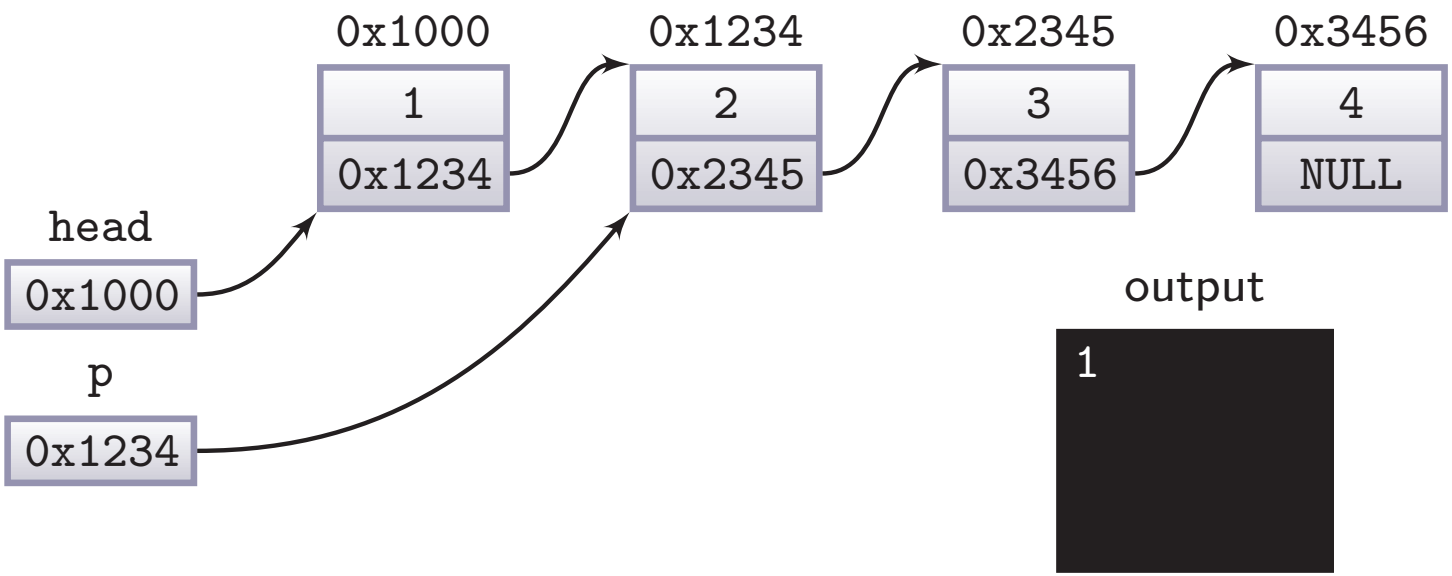

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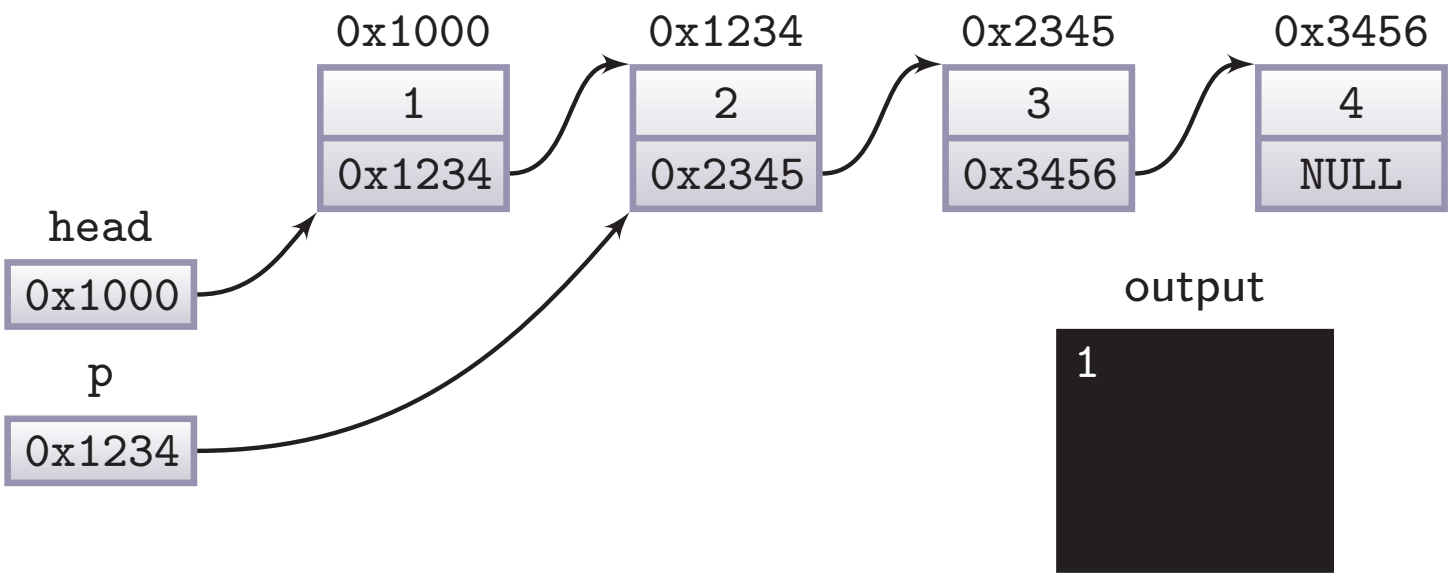

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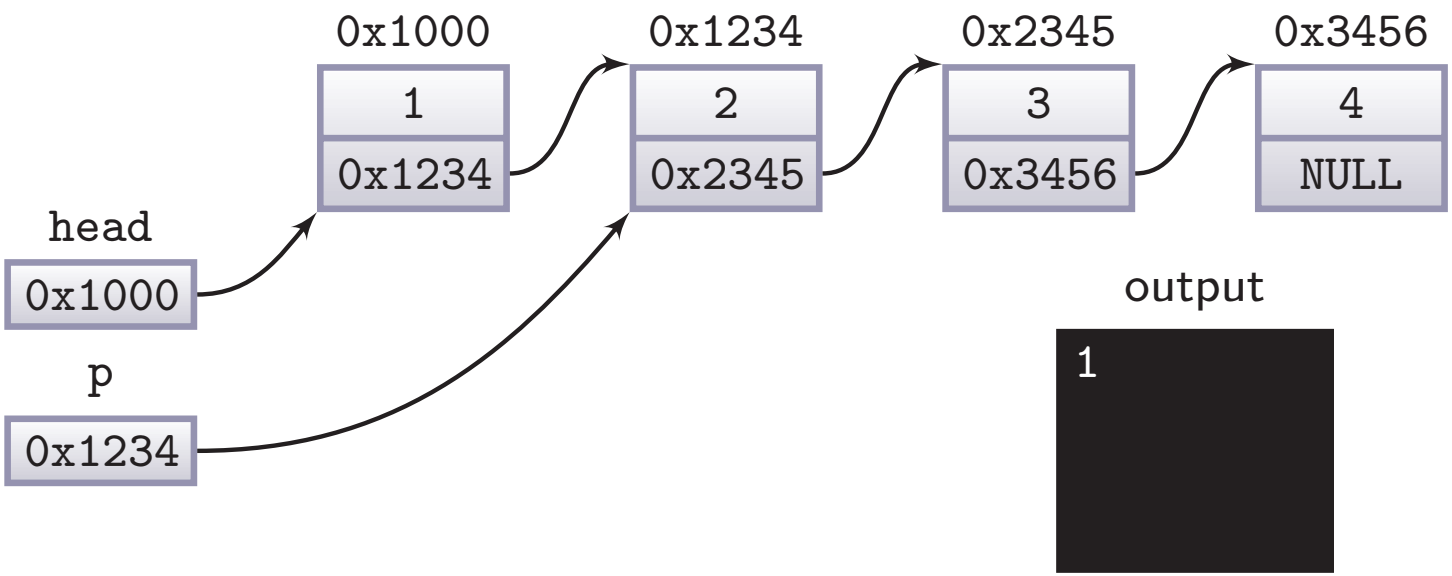

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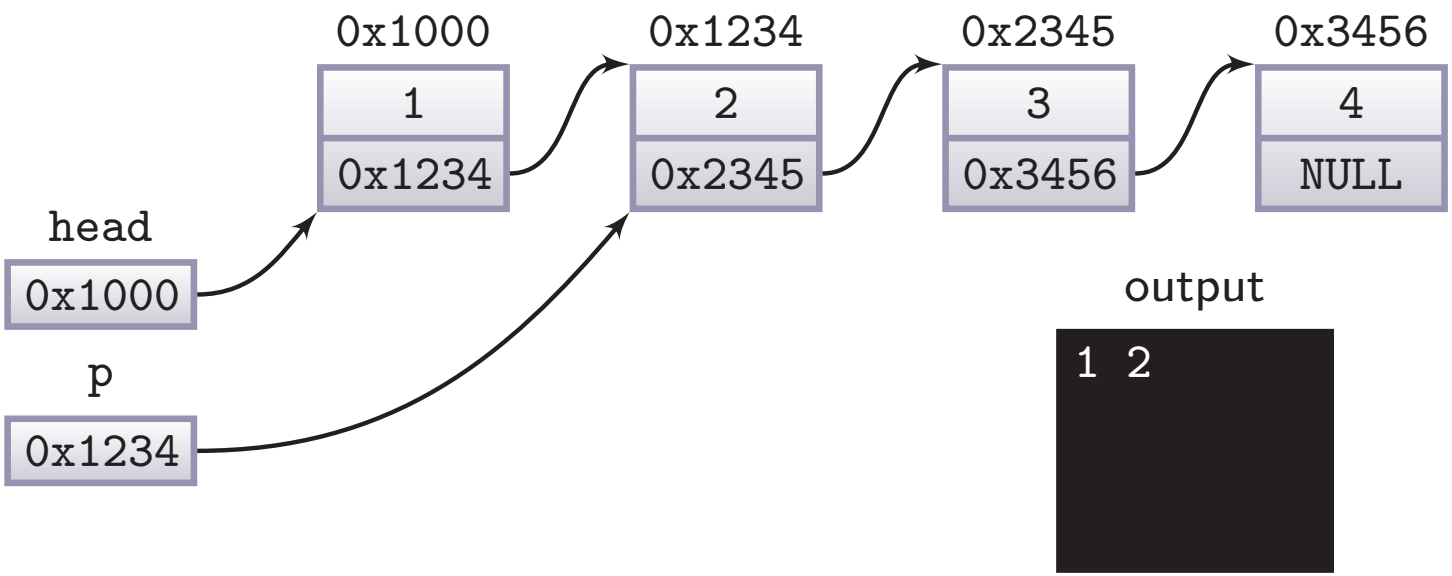

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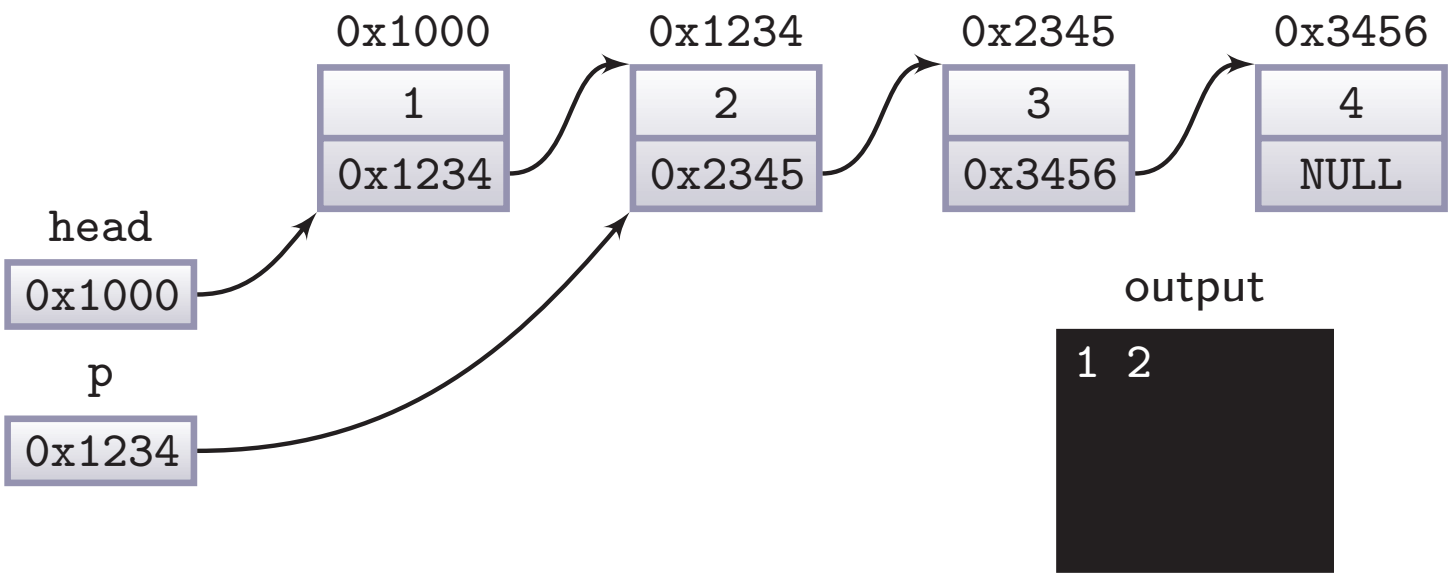

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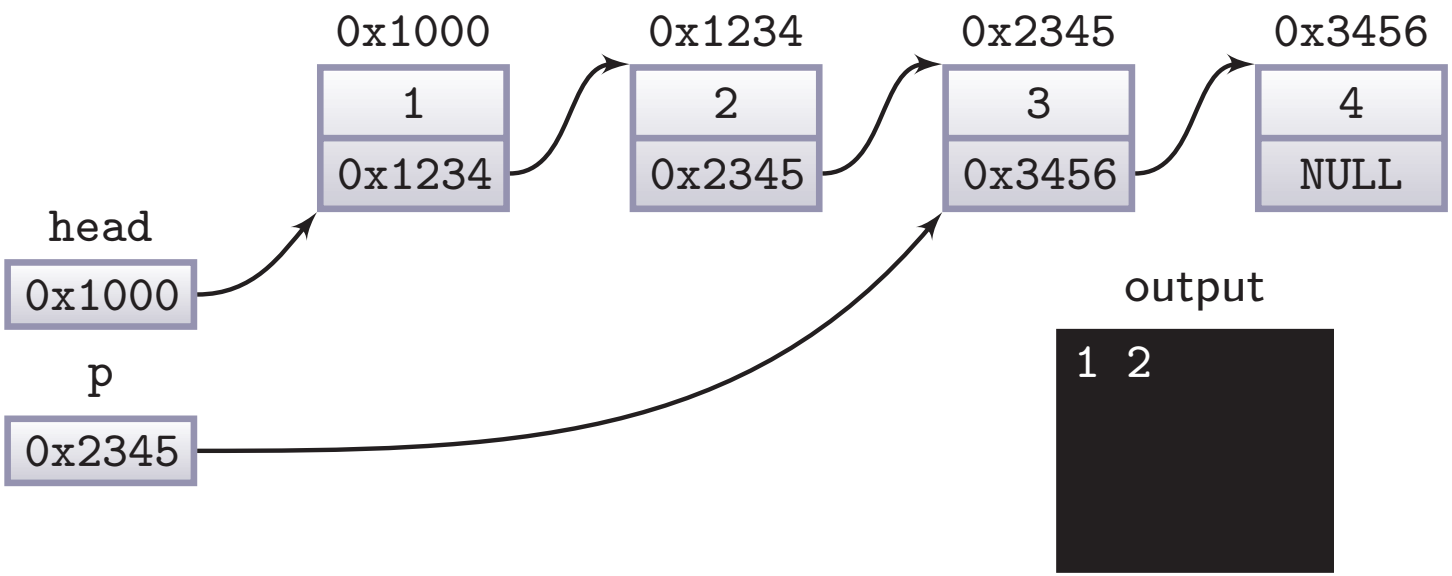

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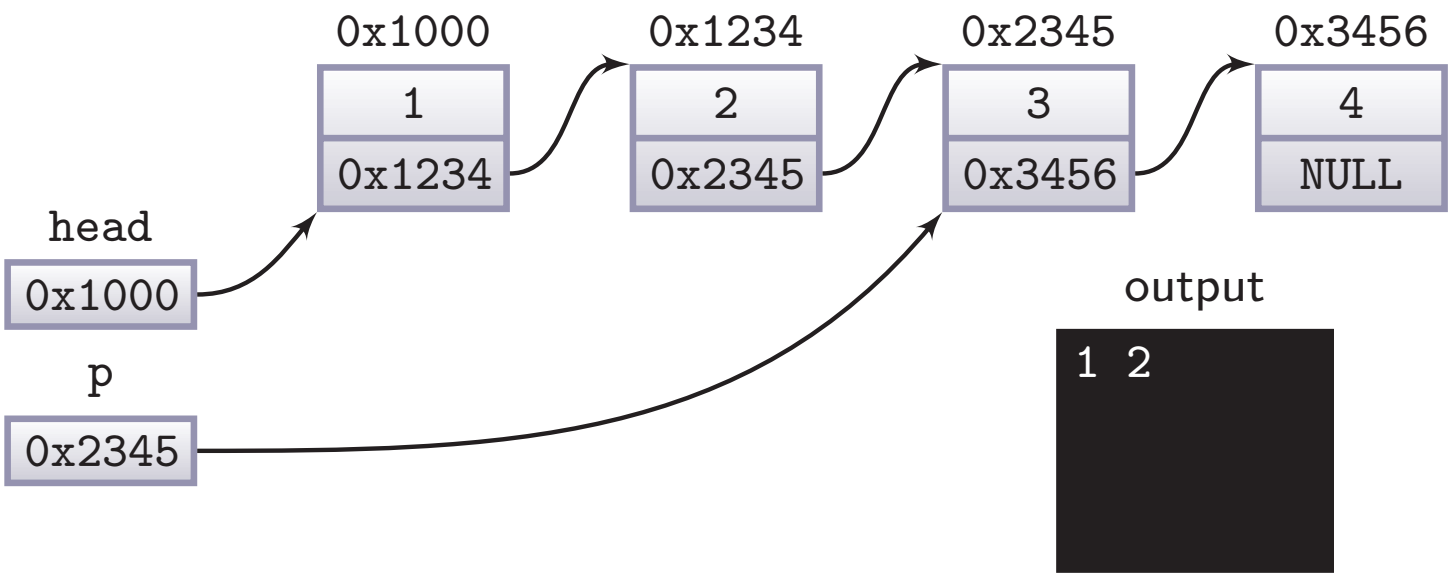

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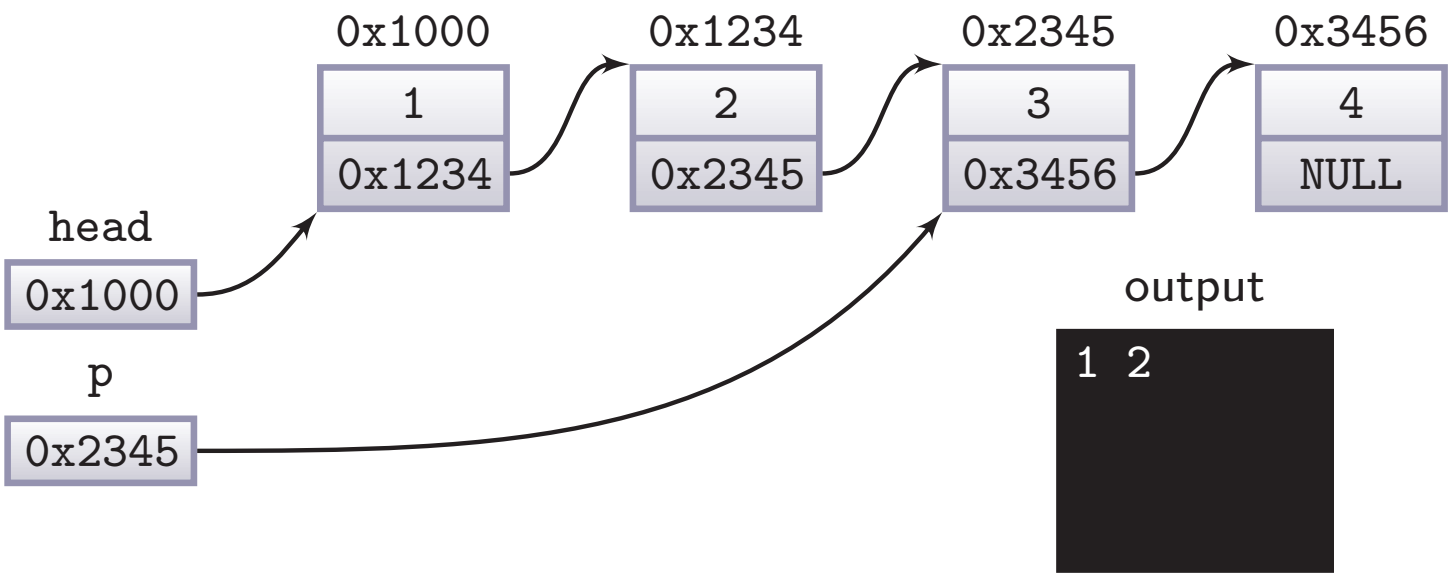

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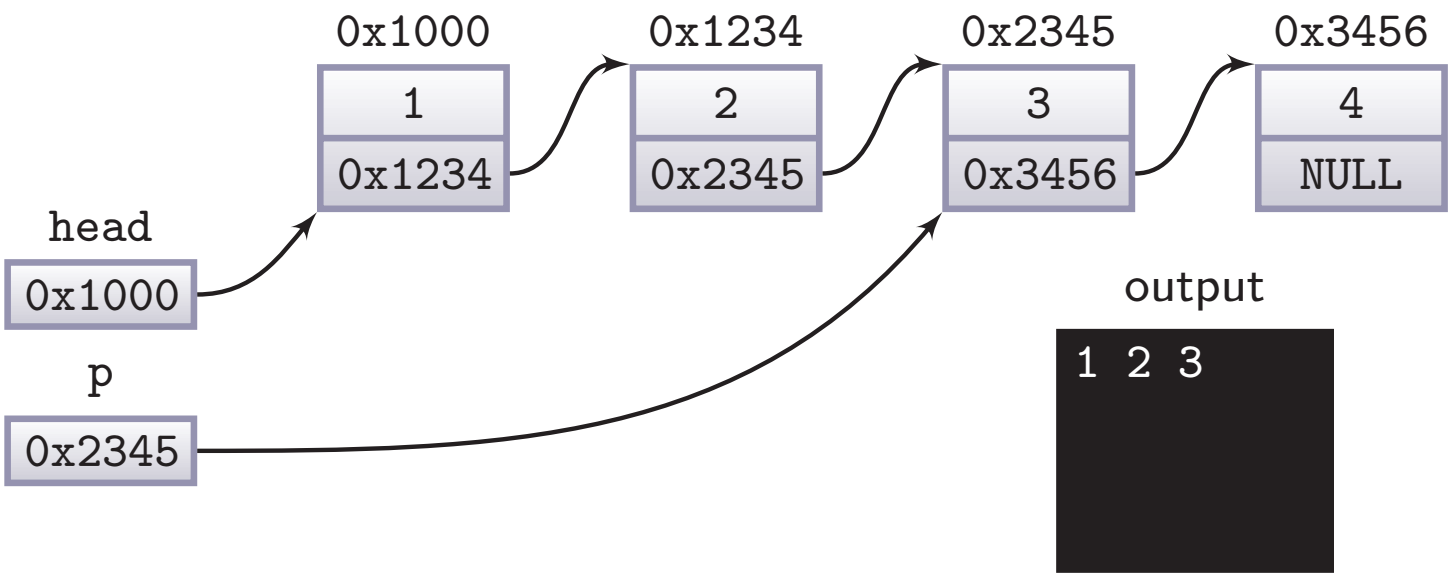

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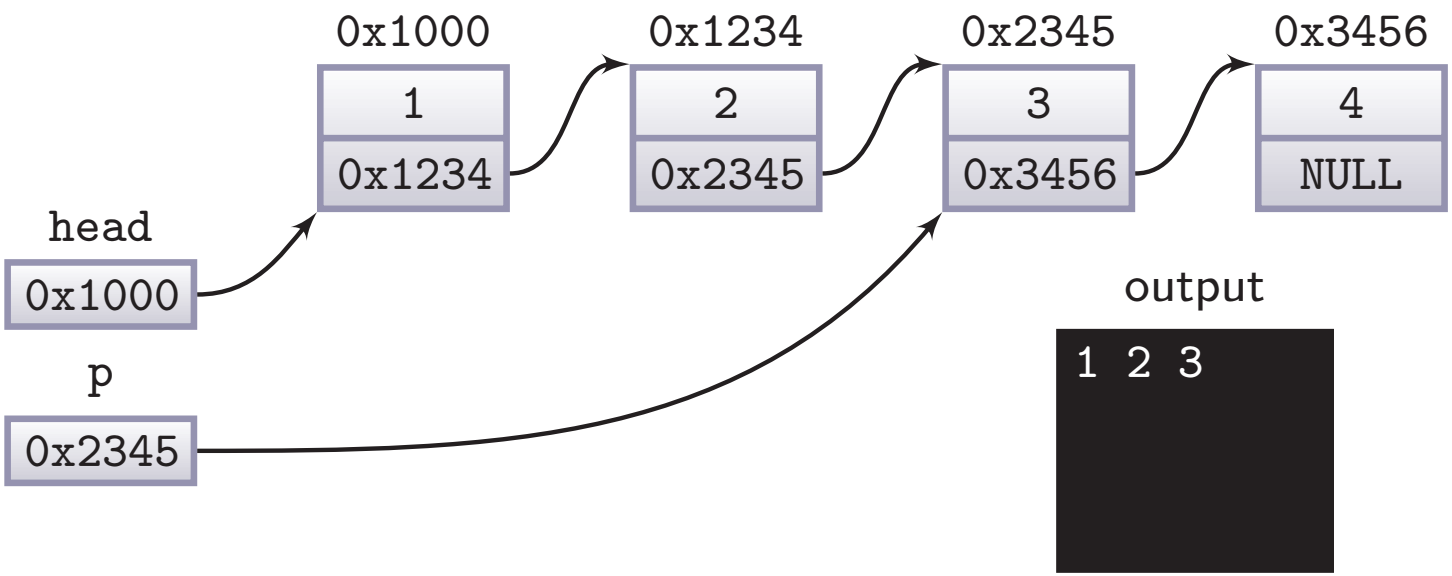

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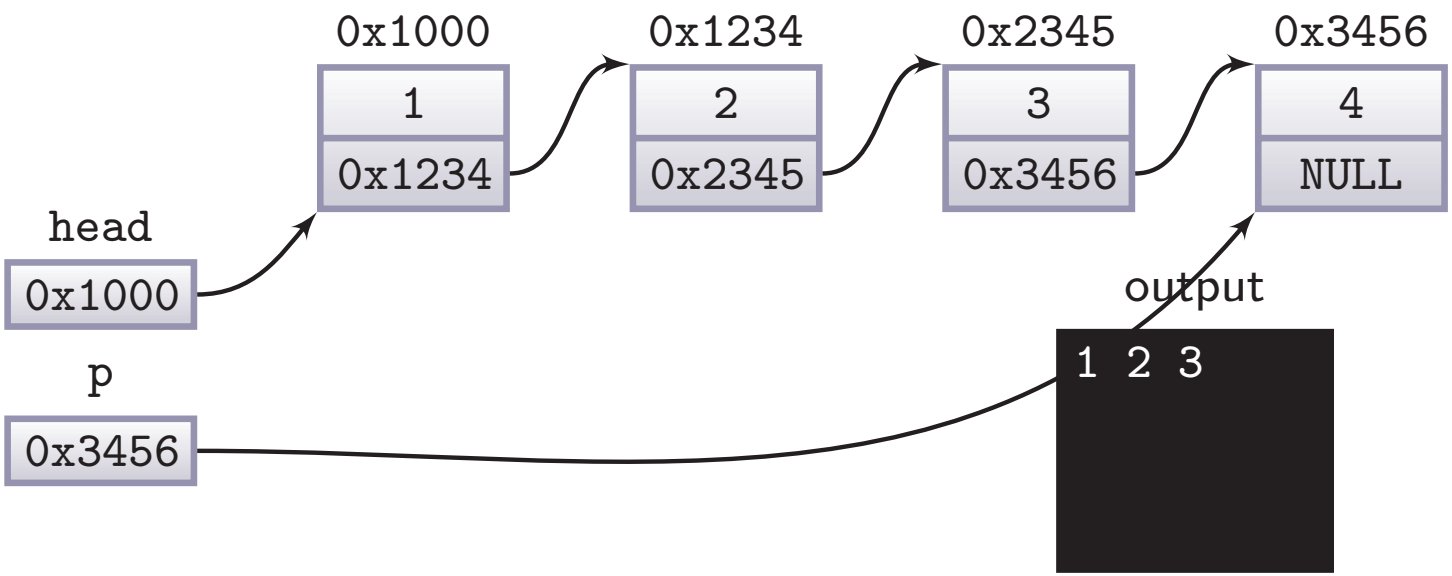

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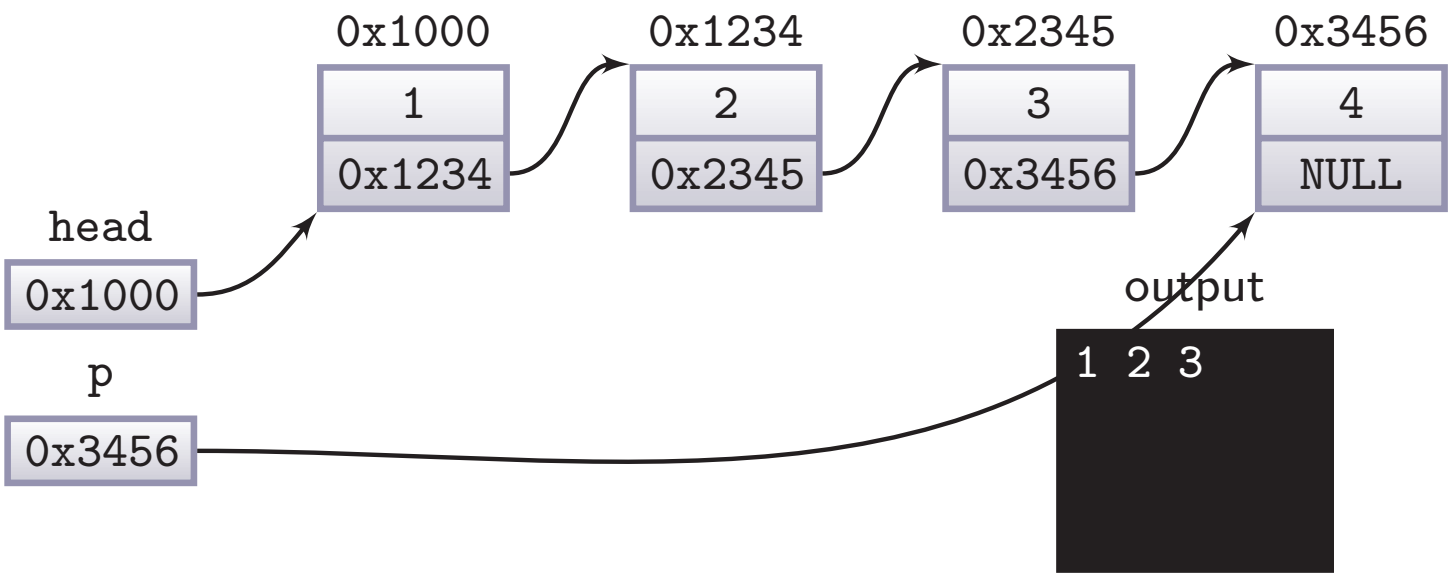

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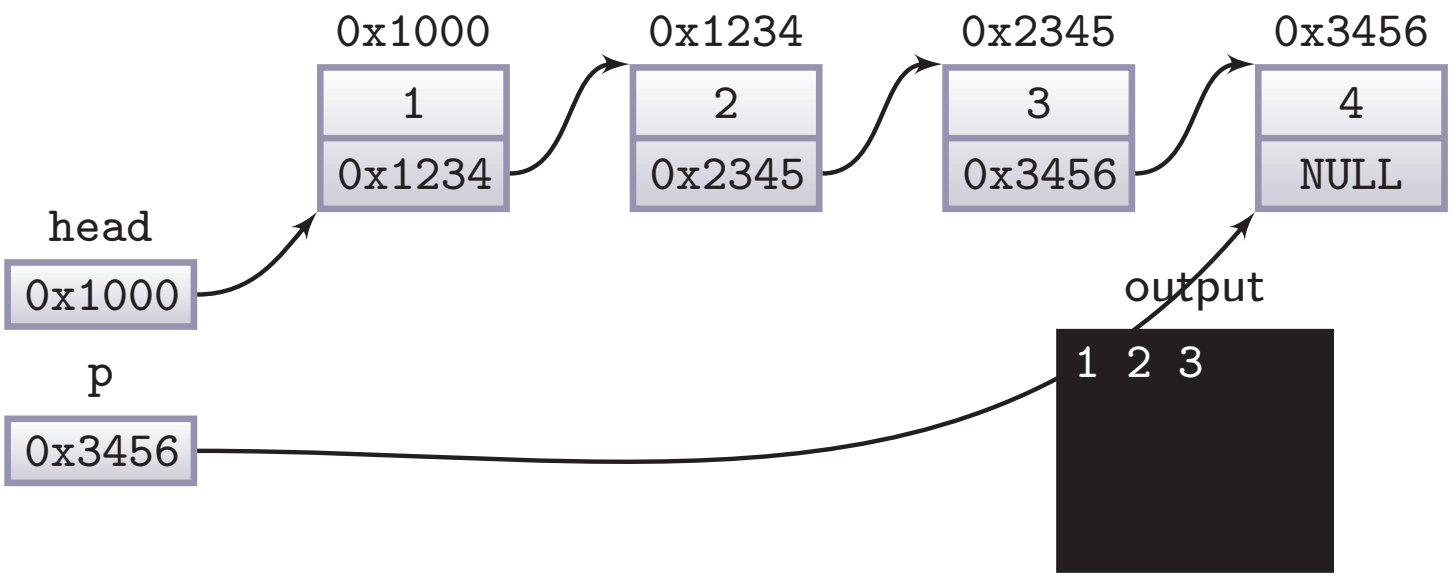

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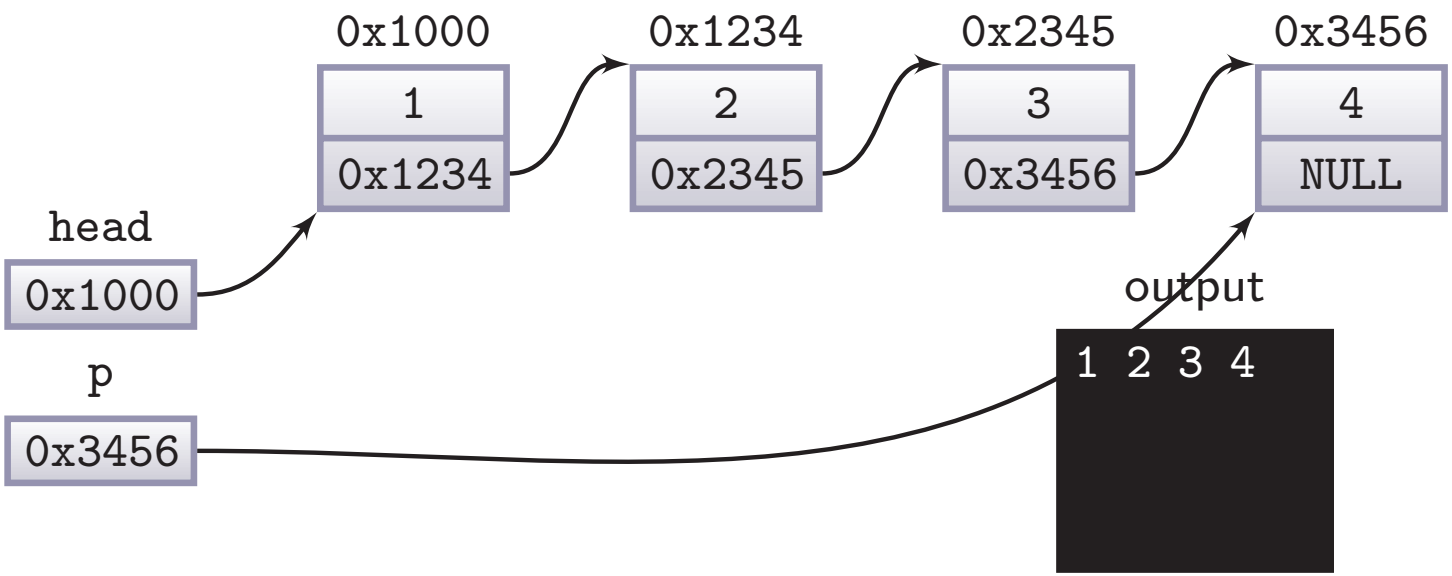

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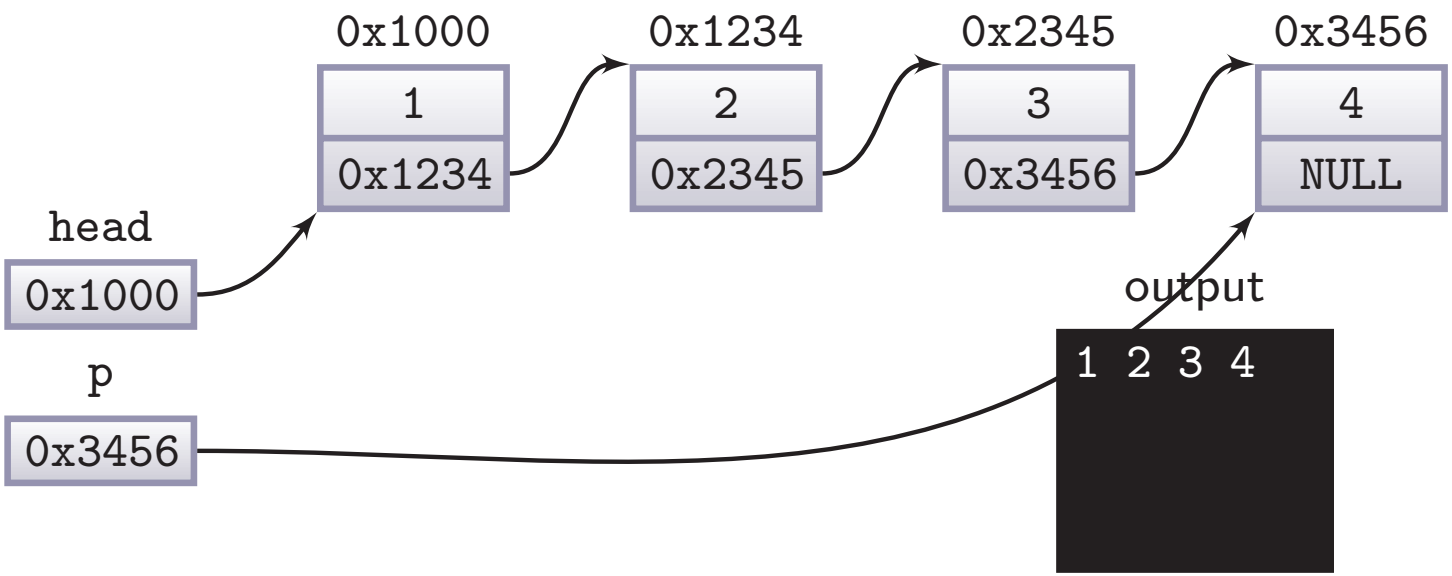

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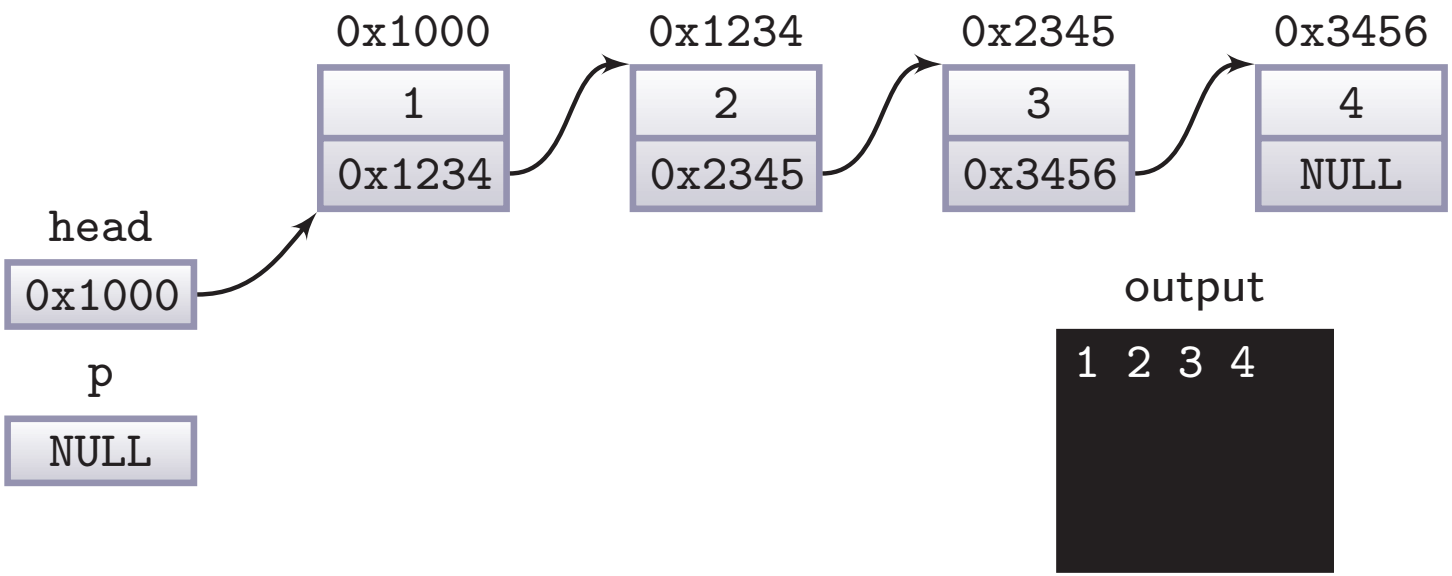

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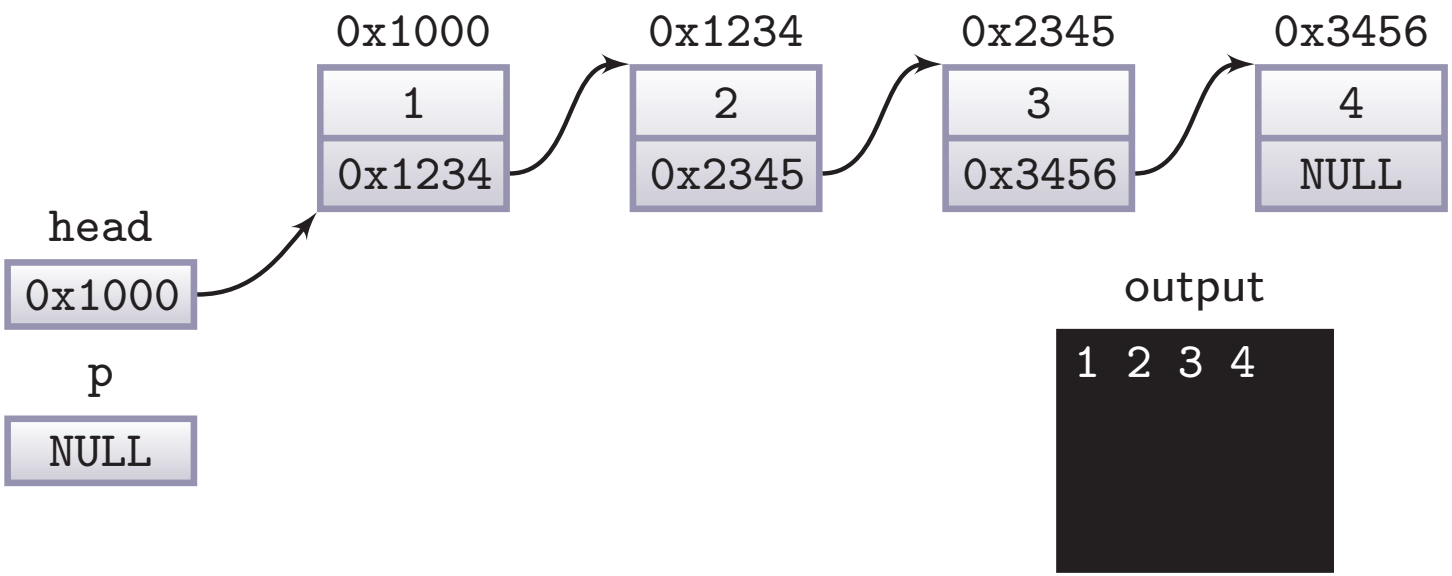
4    printf("%d ", p->data); /* p->data : (*p).data */
5    p = p->next;            /* arrow operator */
6  }
```

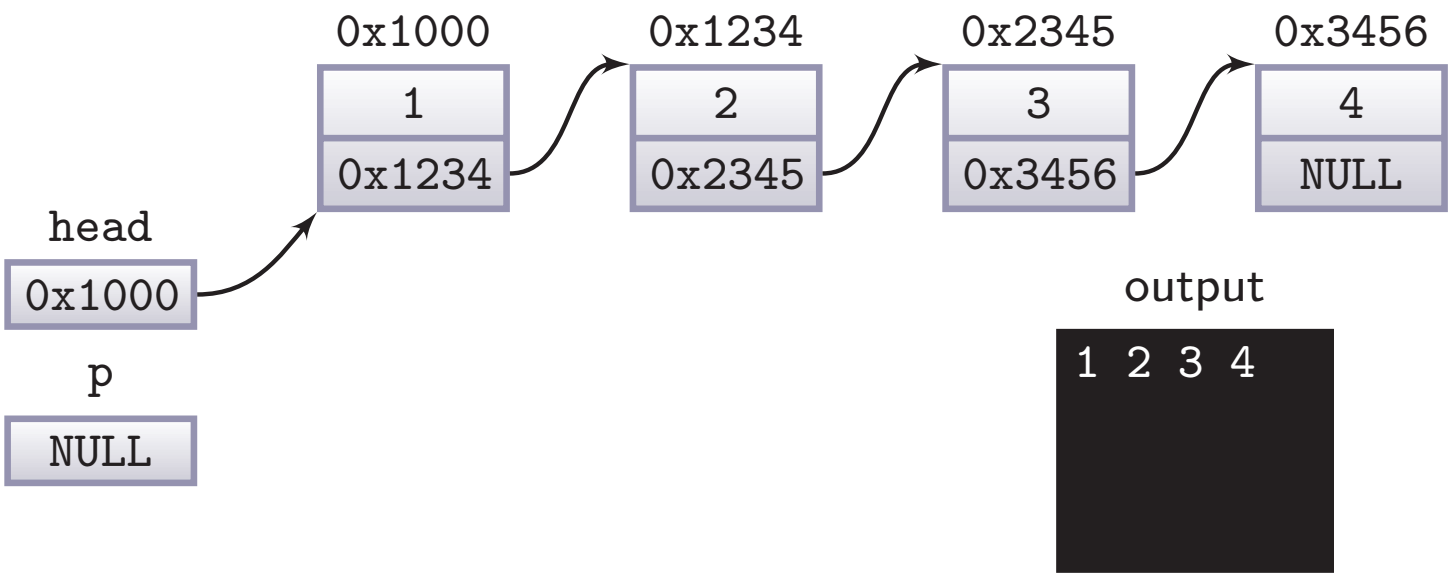


Traversing a list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

- For traversing we need an auxiliary pointer (p), that will run along the list.

```
1  listelem *p = head;
2  while (p != NULL)
3  {
4    printf("%d ", p->data); /* p->data : (*p).data */
5    p = p->next;            /* arrow operator */
6  }
```



Passing a list to a function

- As a list is determined by its starting address, we only need to pass the startig address for the function

```
1  void traverse(listelem *head) {
2    listelem *p = head;
3    while (p != NULL)
4    {
5      printf("%d ", p->data);
6      p = p->next;
7    }
8  }
```

link

Passing a list to a function

- As a list is determined by its starting address, we only need to pass the startig address for the function

```c
void traverse(listelem *head) {
  listelem *p = head;
  while (p != NULL)
  {
    printf("%d ", p->data);
    p = p->next;
  }
}
```

link

- the same with `for` loop

```c
void traverse(listelem *head) {
  listelem *p;
  for (p = head; p != NULL; p = p->next)
    printf("%d ", p->data);
}
```

Inserting element to the front of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  p = (listelem*)malloc(sizeof(listelem));
2  p->data = 5;
3  p->next = head;
4  head = p;
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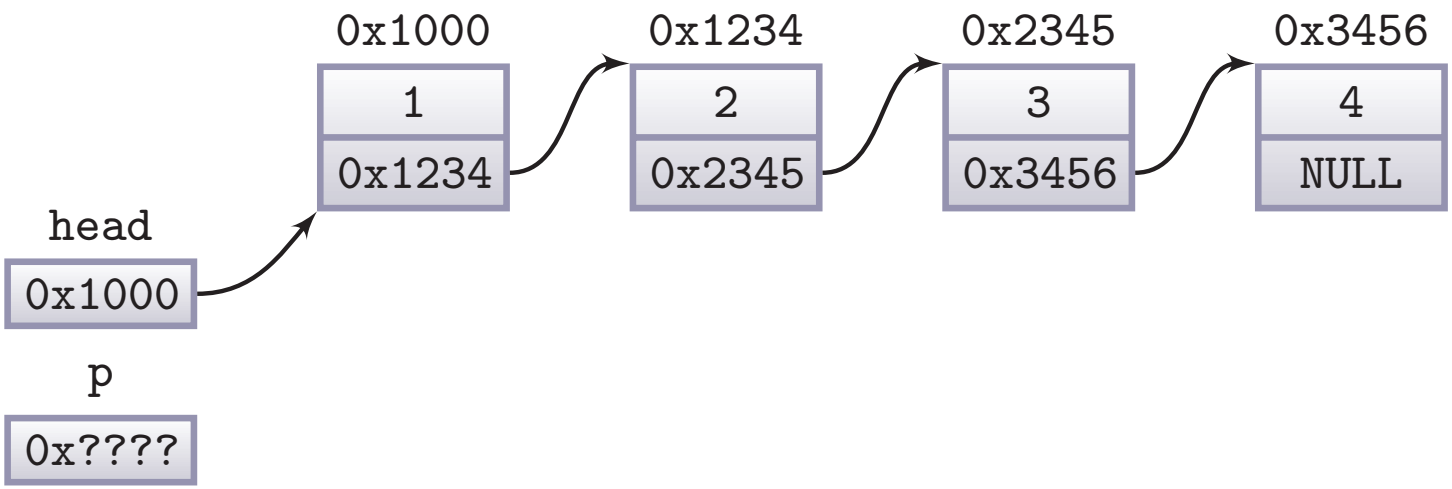

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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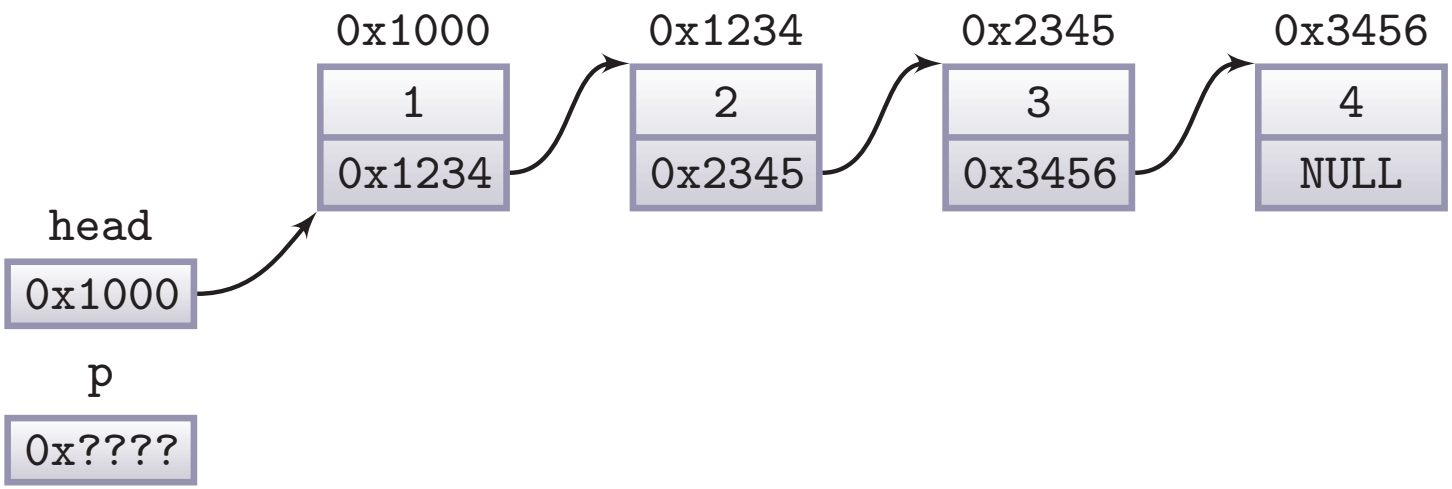

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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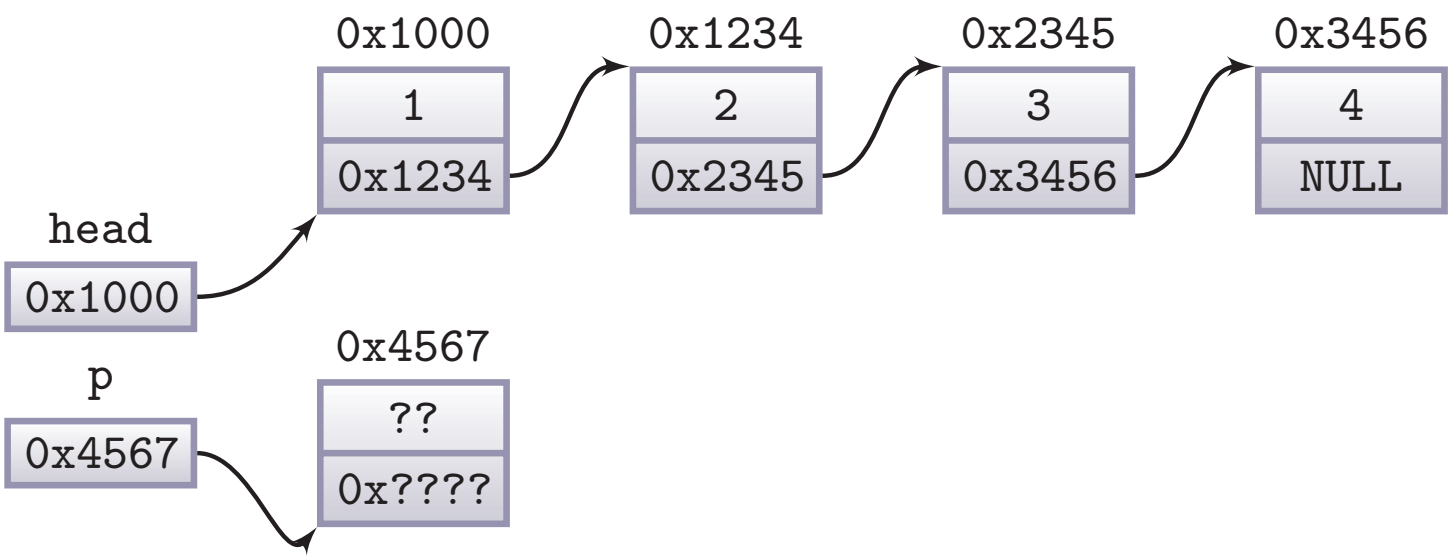

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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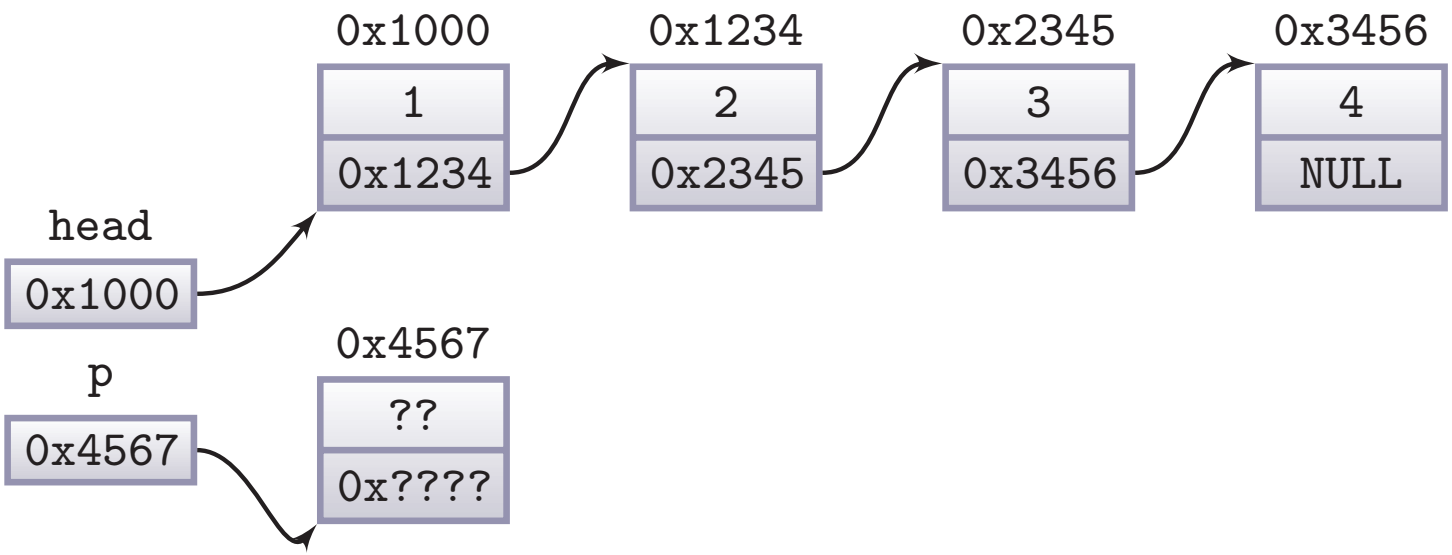

Inserting element to the front of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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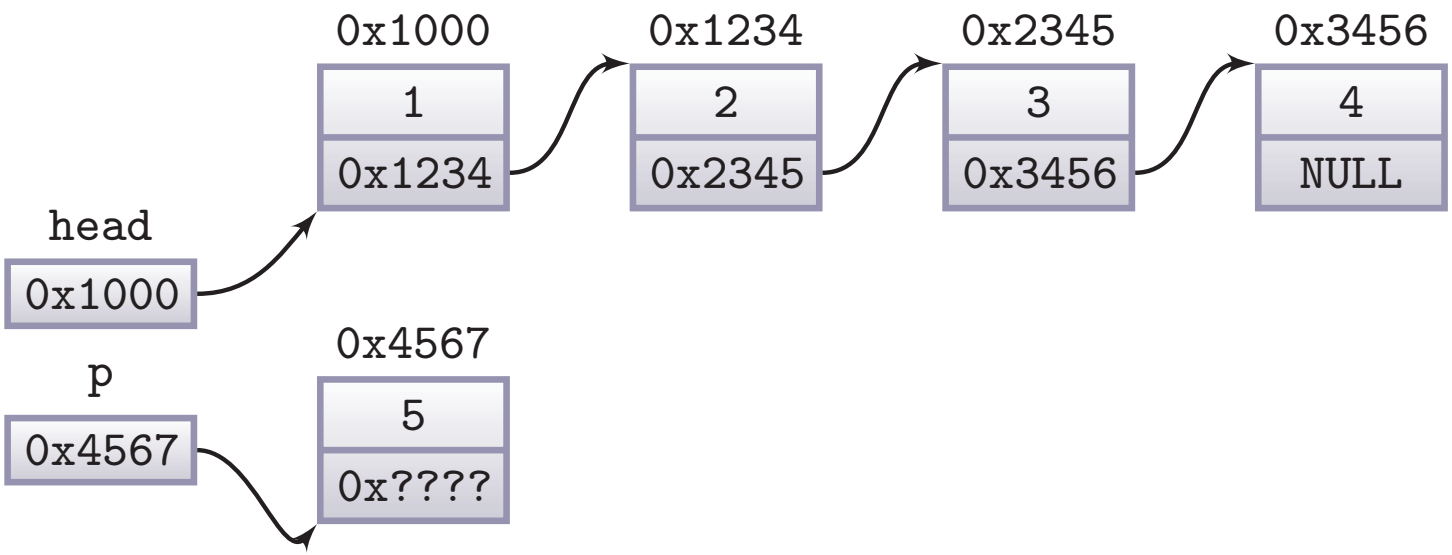

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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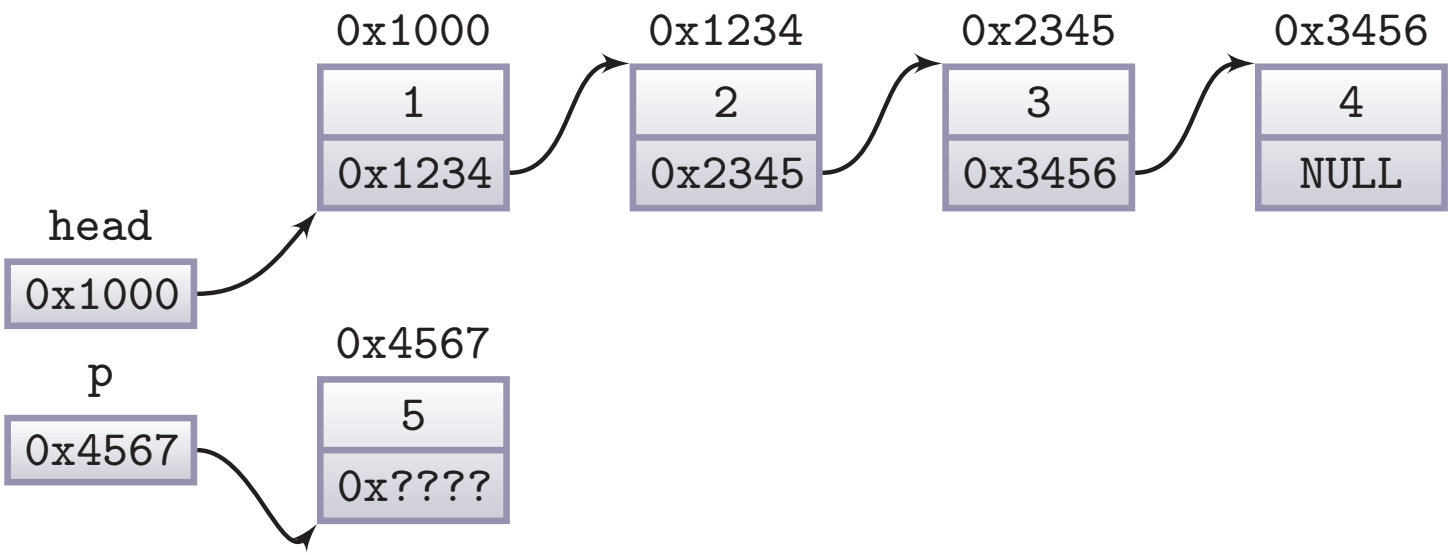

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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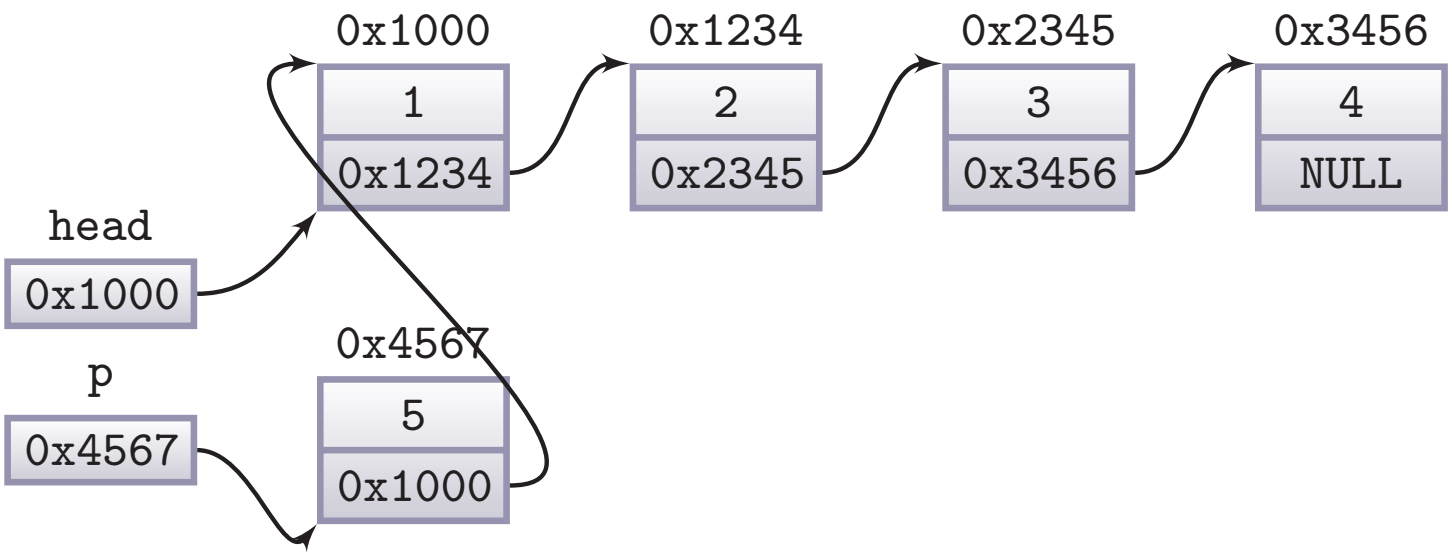

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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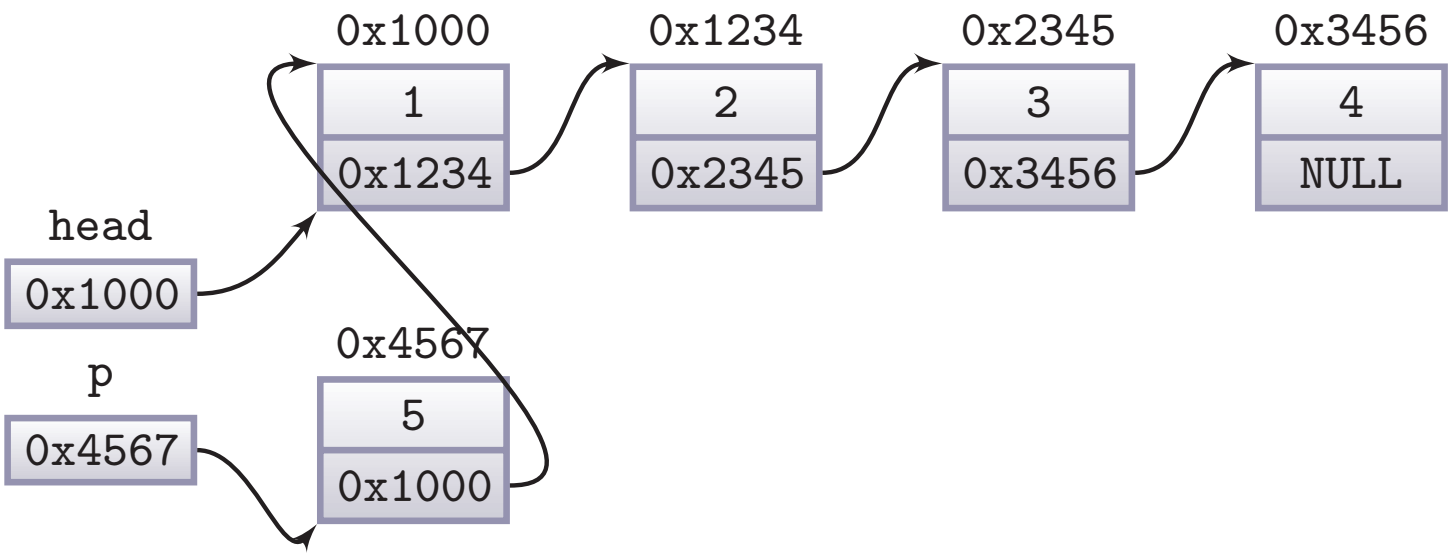

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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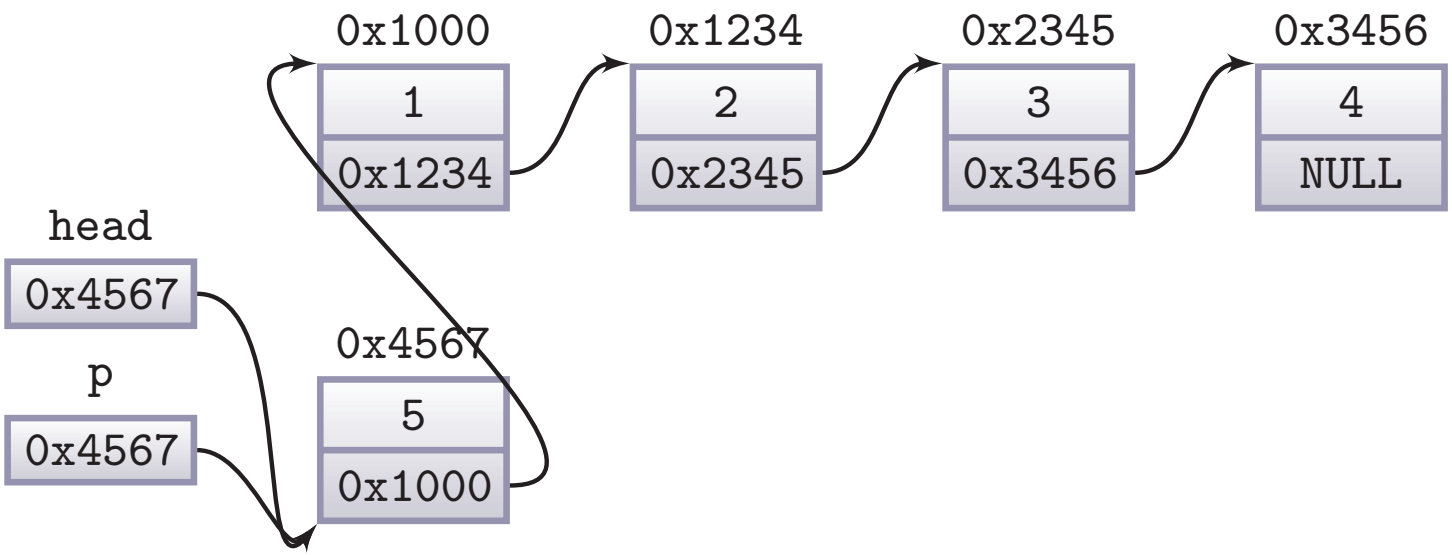

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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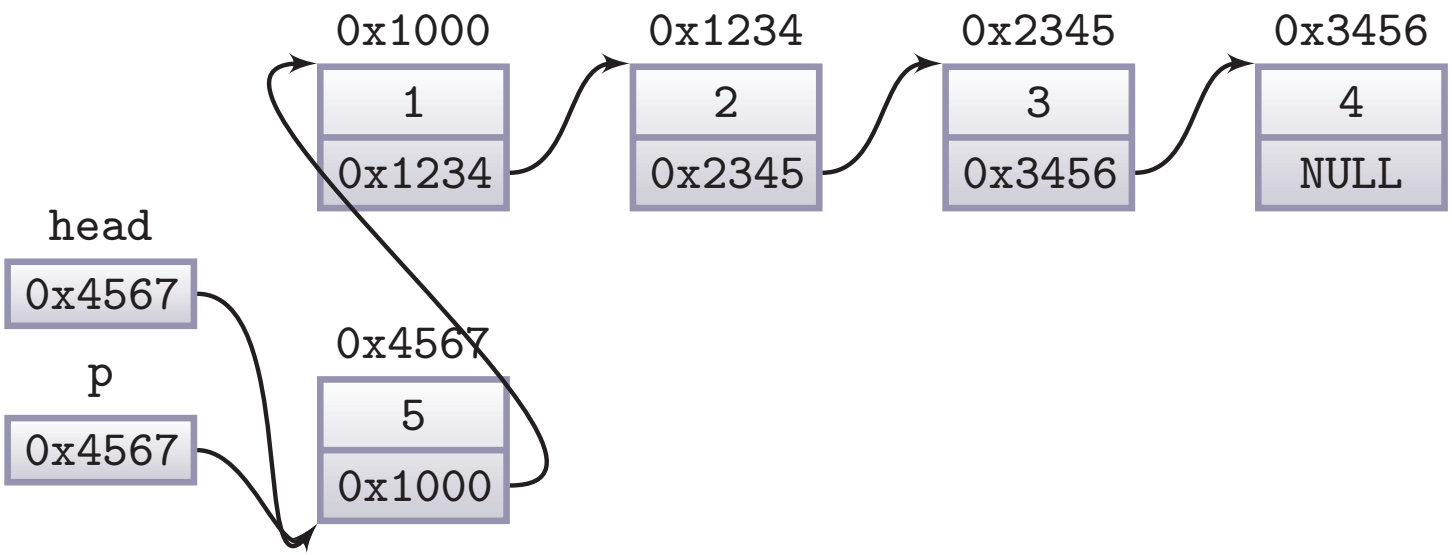

Inserting element to the front of the list, with a function

- As the starting address is changed when inserting, we have to return it (pass it back)

```
1  listelem *push_front(listelem *head, int d)
2  {
3    listelem *p = (listelem*)malloc(sizeof(listelem));
4    p->data = d;
5    p->next = head;
6    head = p;
7    return head;
8  }
```

link

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4    p->data = d;
5    p->next = head;
6    head = p;
7    return head;
8  }
```

link

- Usage of function

```
1  listelem *head = NULL;          /* empty list */
2  head = push_front(head, 2);     /* head is changed! */
3  head = push_front(head, 4);
```

Inserting element to the front of the list, with a function

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

- Another option is to pass the starting address by its address

```
1  void push_front(listelem **head, int d)
2  {
3    listelem *p = (listelem*)malloc(sizeof(listelem));
4    p->data = d;
5    p->next = *head;
6    *head = p; /* *head is changes, this is not lost */
7  }
```

link

Inserting element to the front of the list, with a function

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```
1  void push_front(listelem **head, int d)
2  {
3    listelem *p = (listelem*)malloc(sizeof(listelem));
4    p->data = d;
5    p->next = *head;
6    *head = p; /* *head is changes, this is not lost */
7  }
```

link

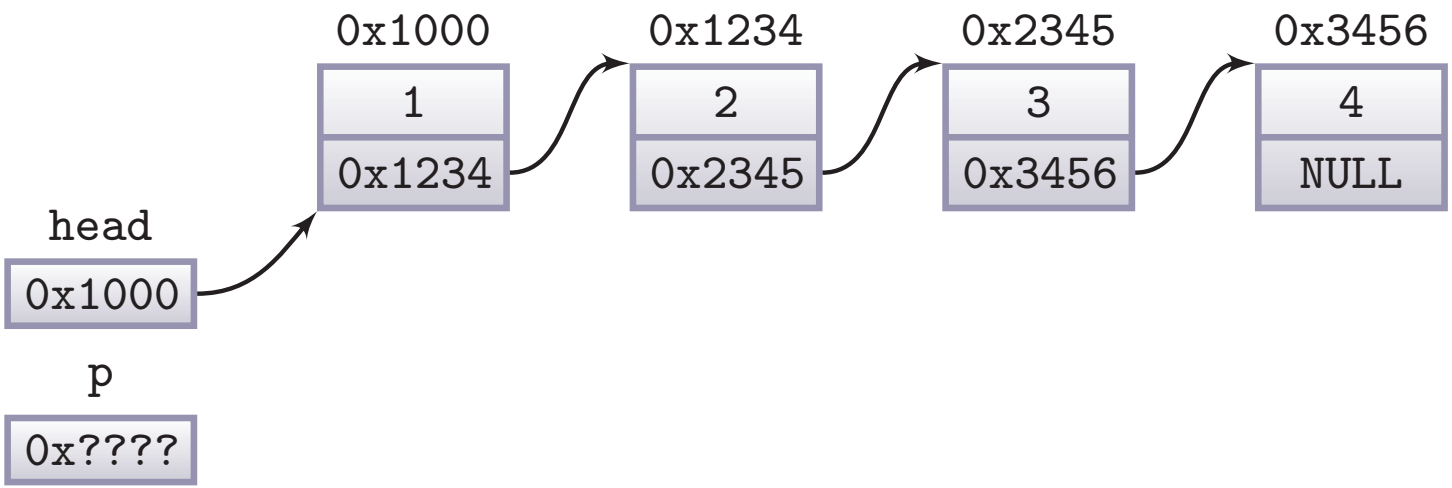
- In this case the usage of the function is:

```
1  listelem *head = NULL;   /* empty list */
2  push_front(&head, 2);    /* calling with address */
3  push_front(&head, 4);
```

Deleting element from the front of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  p = head;
2  head = head->next;
3  free(p);
```



Deleting element from the front of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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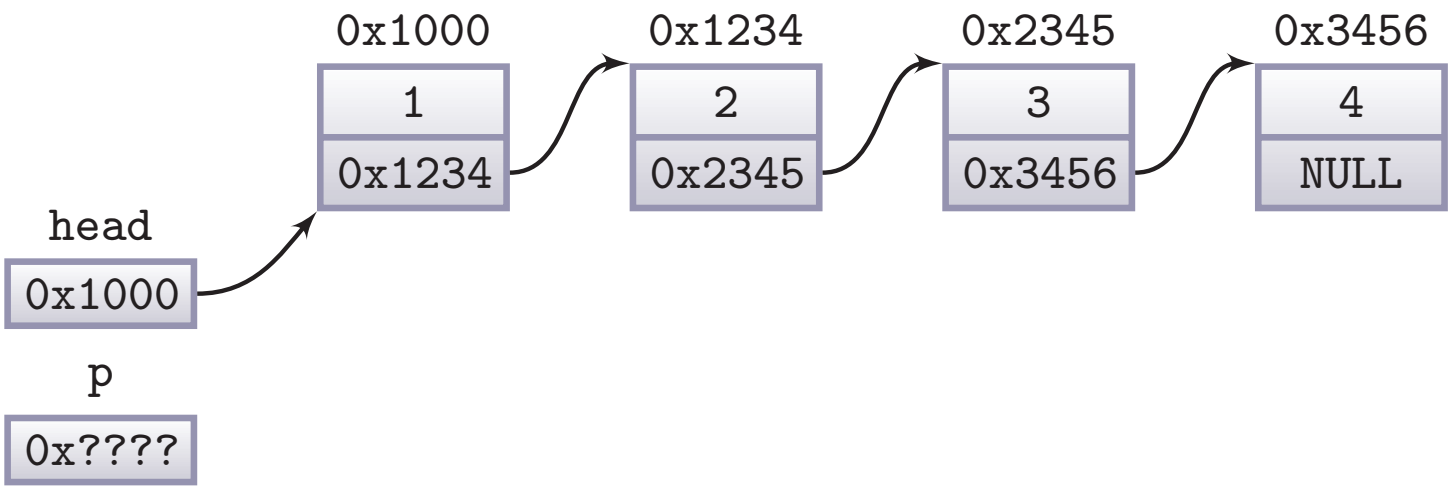

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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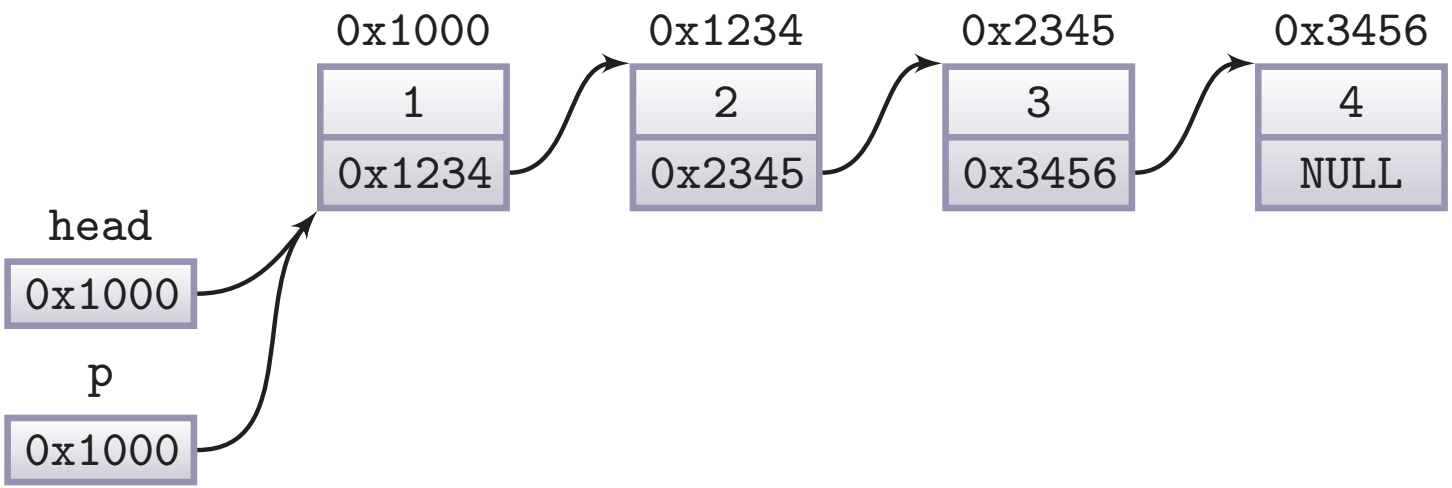

Deleting element from the front of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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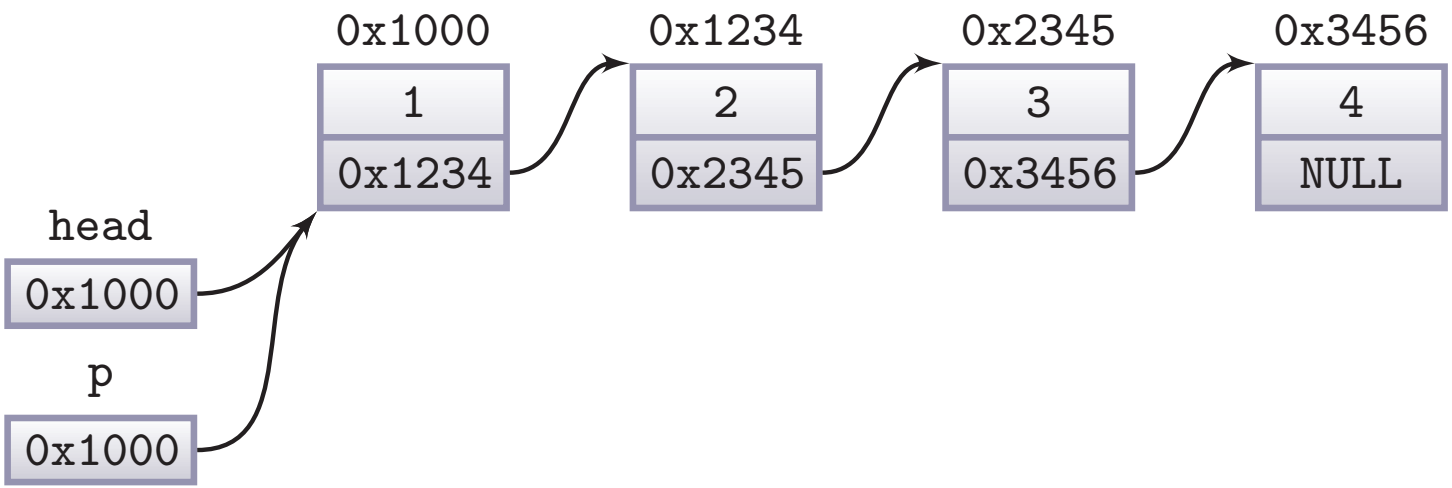

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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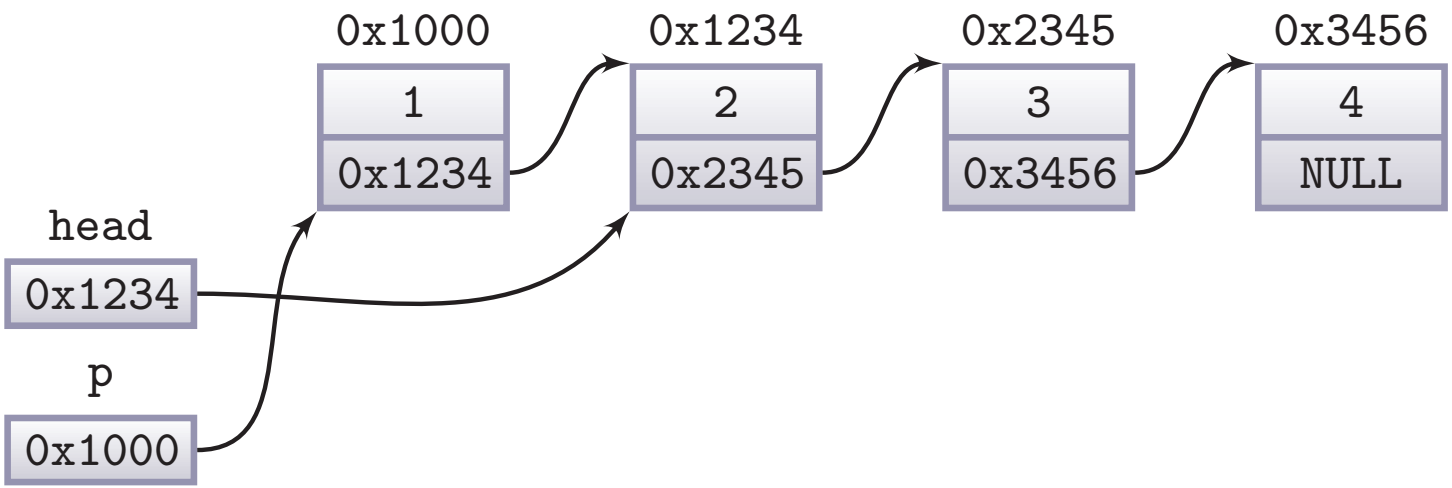

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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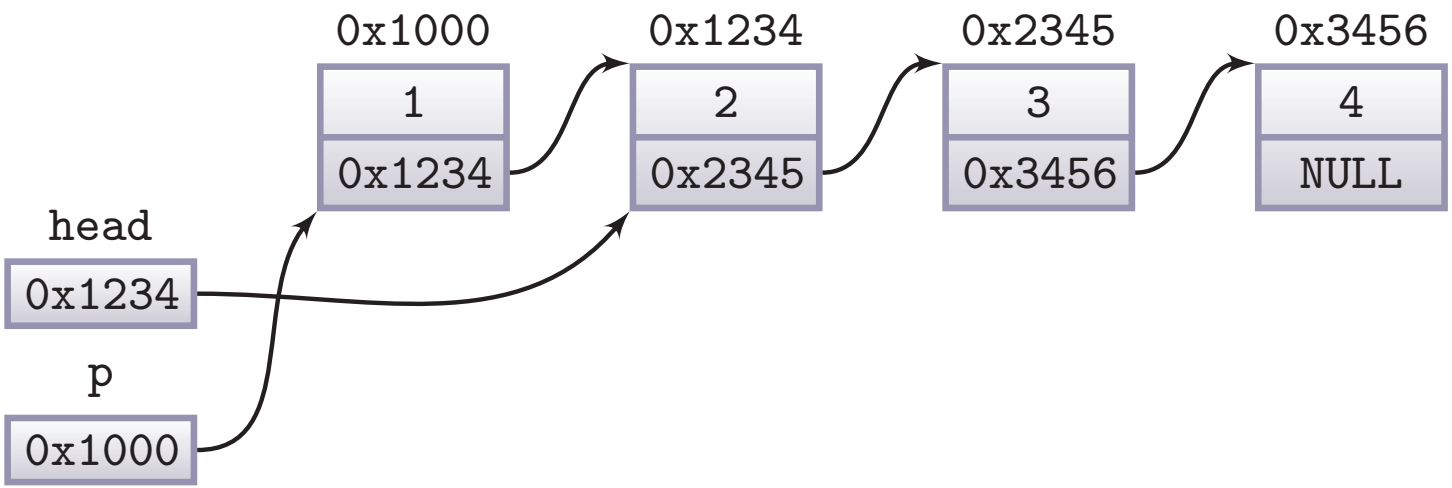

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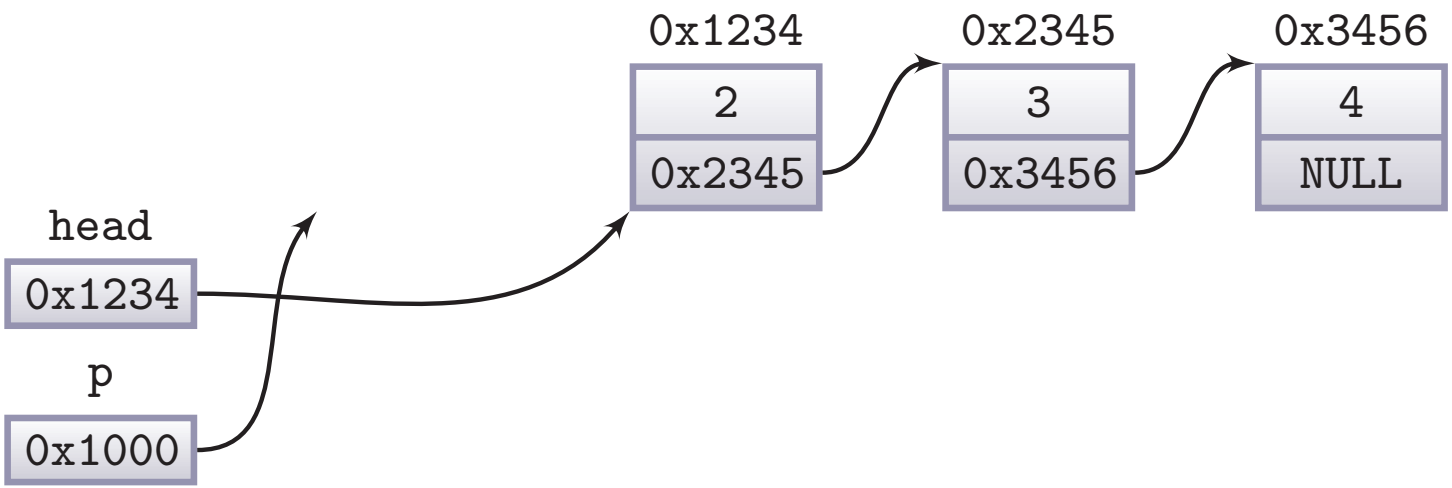

Deleting element from the front of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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3  free(p);
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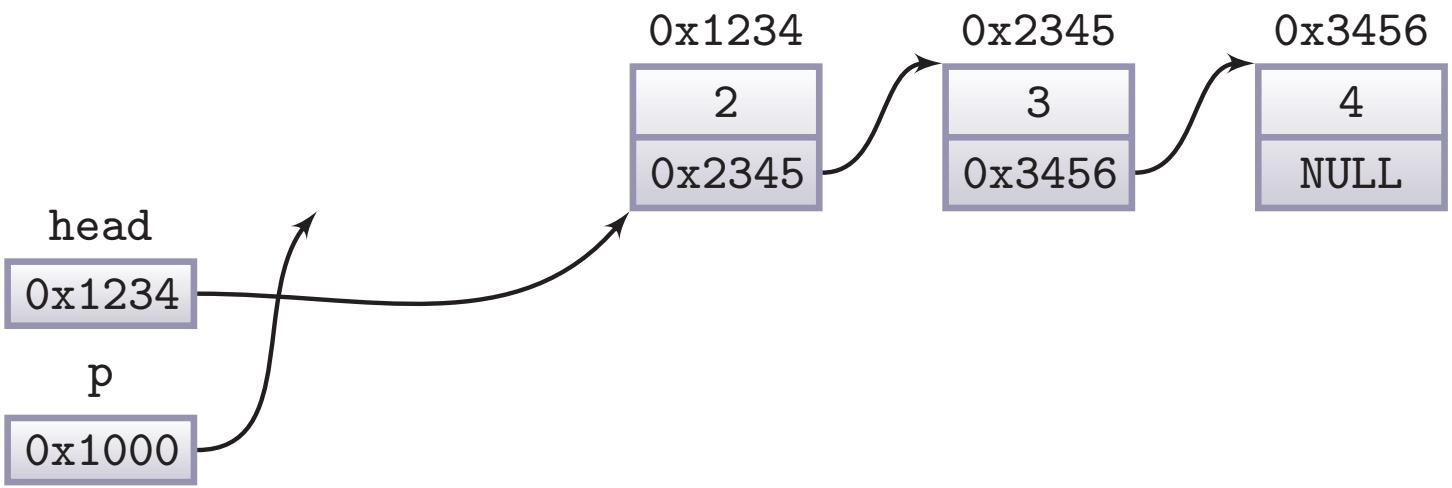


Deleting element from front of the list with a function

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  listelem *pop_front(listelem *head)
2  {
3    if (head != NULL) /* not empty */
4    {
5      listelem *p = head;
6      head = head->next;
7      free(p);
8    }
9    return head;
10 }
```

link

- An empty list must be handled separately

Deleting element from front of the list with a function

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  listelem *pop_front(listelem *head)
2  {
3    if (head != NULL) /* not empty */
4    {
5      listelem *p = head;
6      head = head->next;
7      free(p);
8    }
9    return head;
10 }
```

link

- An empty list must be handled separately
- Of course we could use the solution when calling the functionwith the address of `head`

Stack

- What we have so far is already enough for storing the undo-list

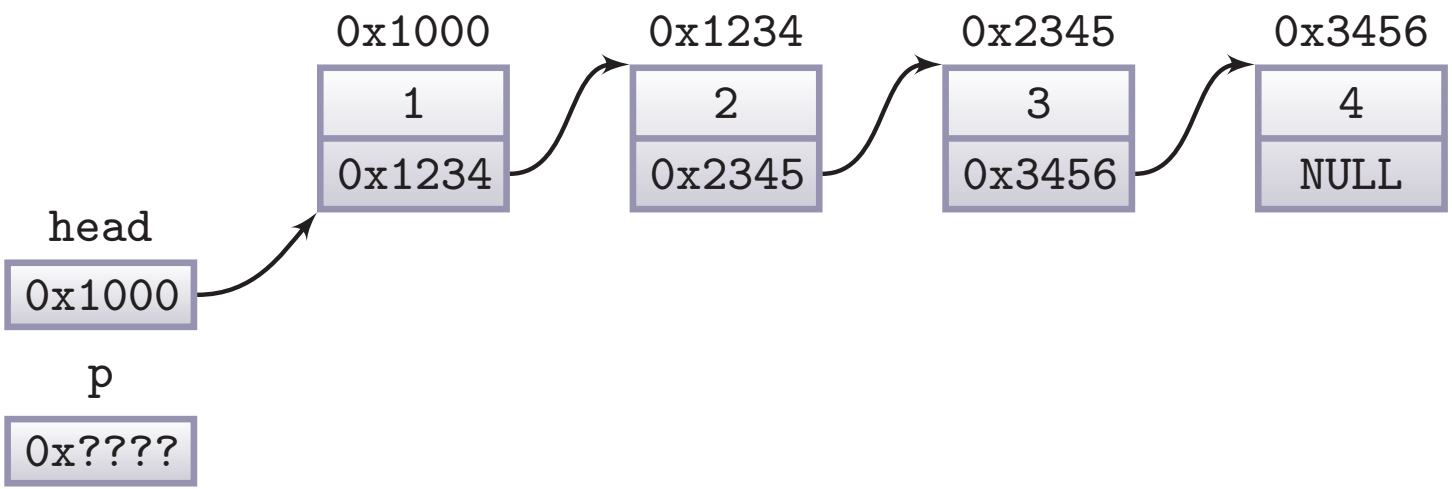
```
1  listelem *head = NULL;                  /* empty list */
2  head = push_front(head, 2);             /* step */
3  head = push_front(head, 4);             /* step */
4  printf("The last inserted element: %d\n", head->data);
5  head = pop_front(head);                 /* undo */
6  head = push_front(head, 5);             /* step */
7  head = pop_front(head);                 /* step */
8  head = pop_front(head);                 /* strep */
```

- The stack is a LIFO: Last In, First Out
- We can access the last inserted element first

Inserting element to the end of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  for (p = head; p->next != NULL; p = p->next);
2  p->next = (listelem*)malloc(sizeof(listelem));
3  p->next->data = 5;
4  p->next->next = NULL;
```



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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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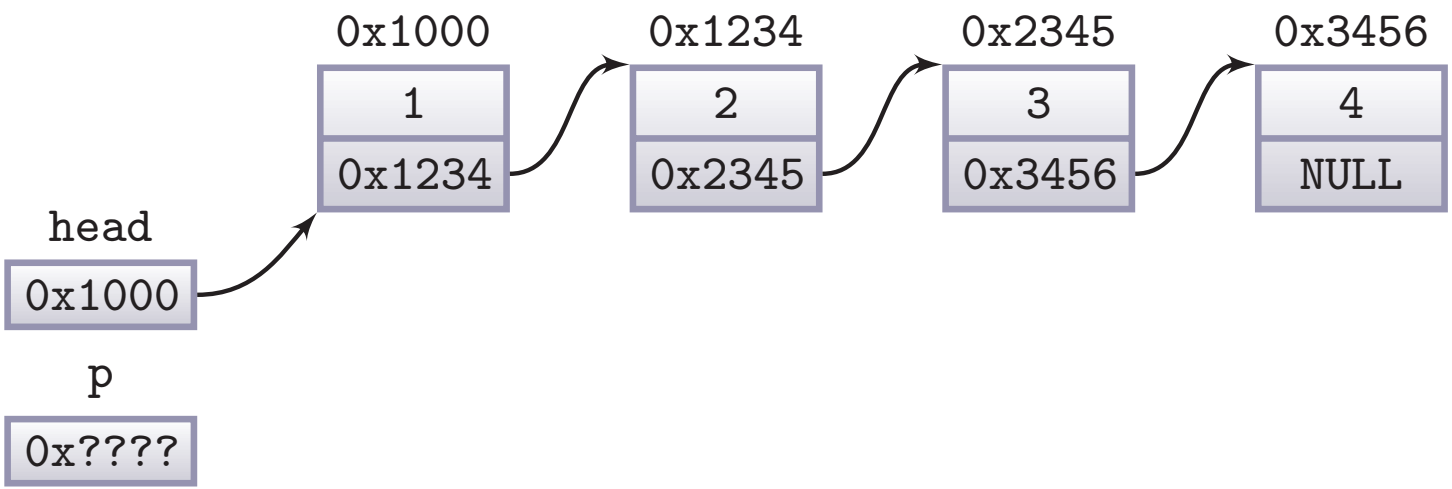

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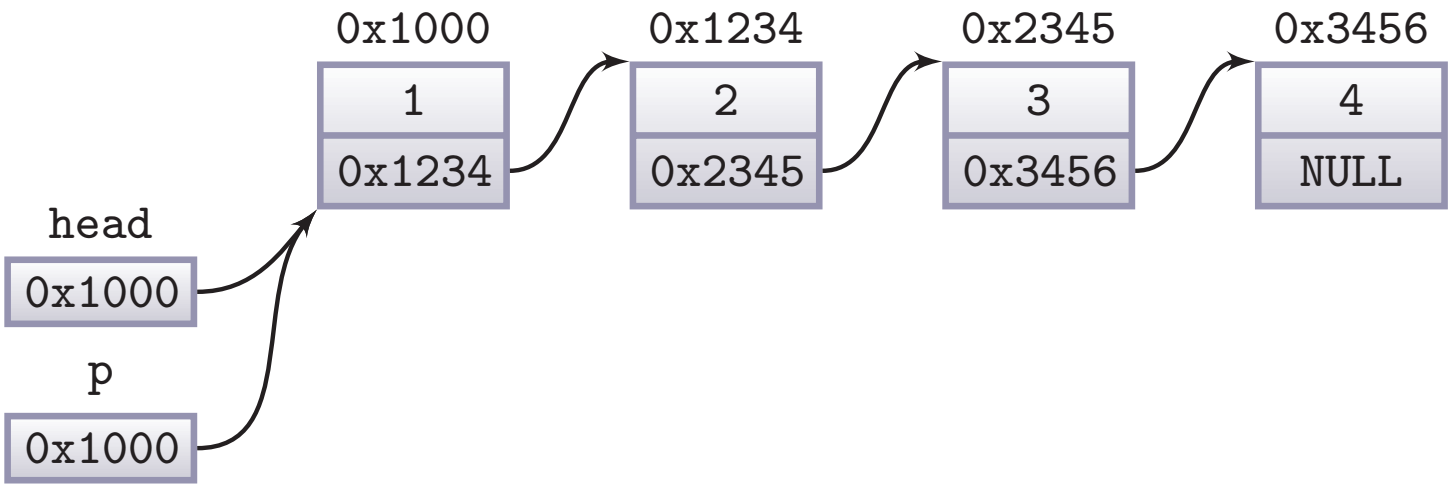

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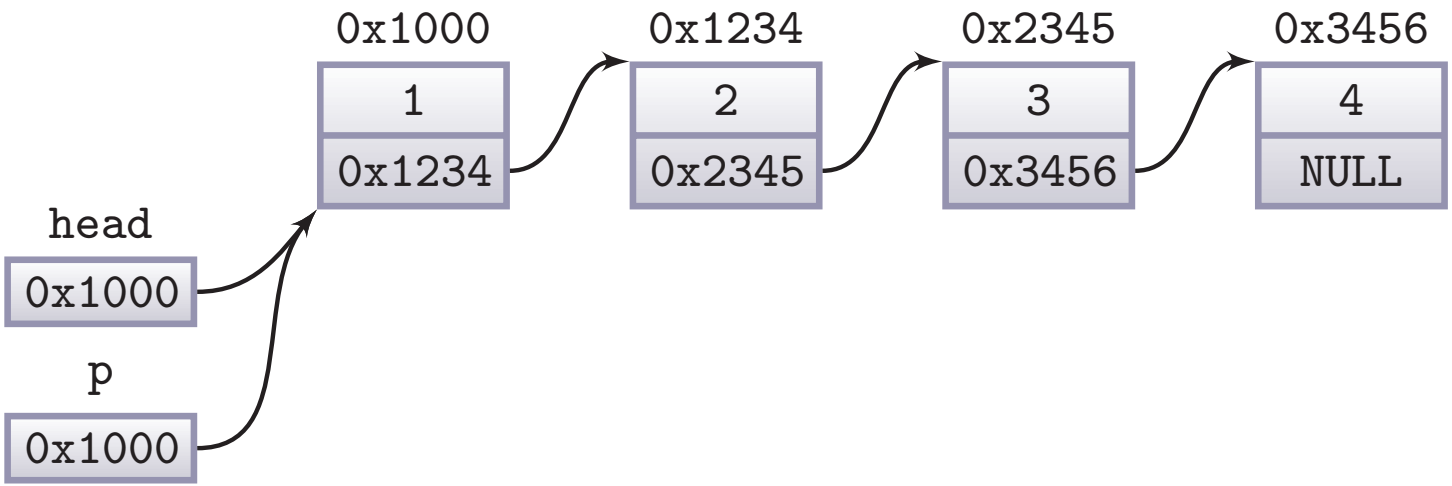

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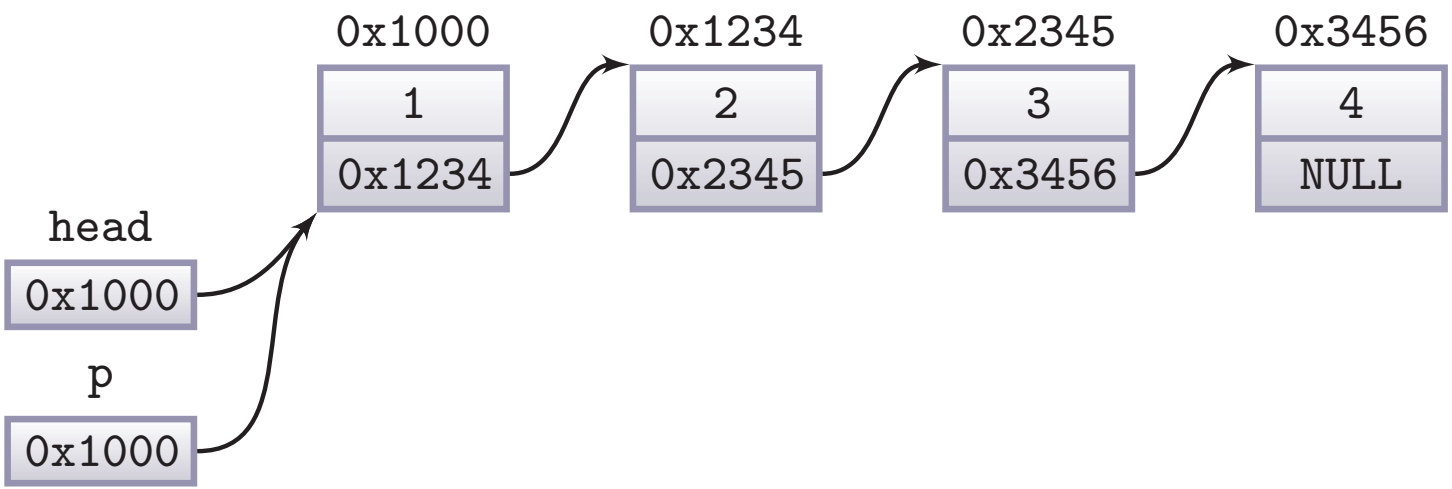

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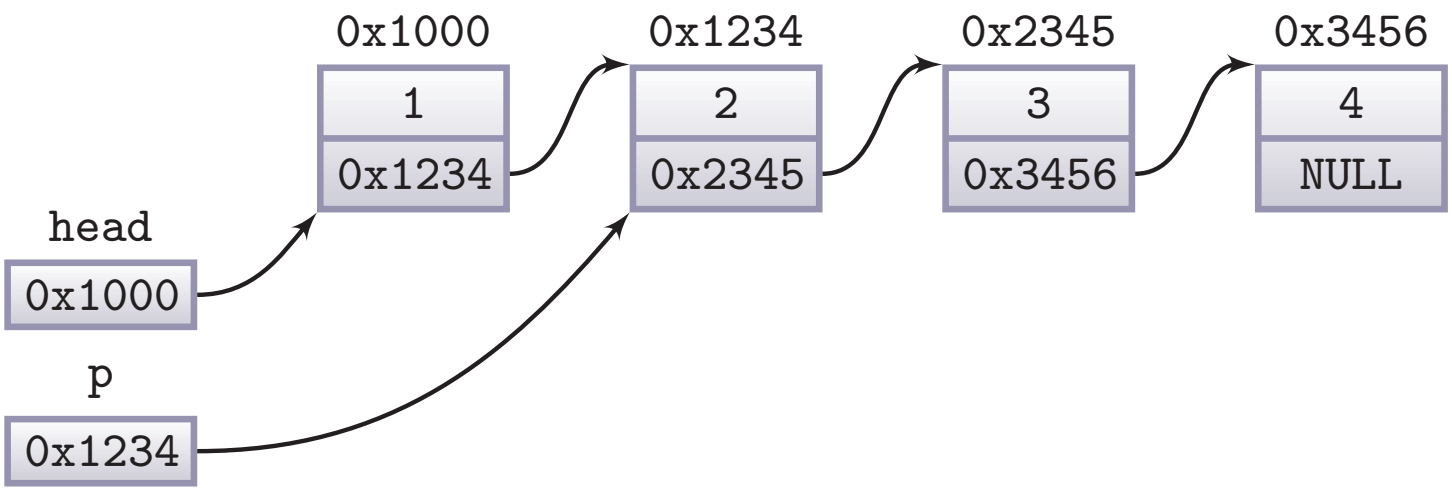

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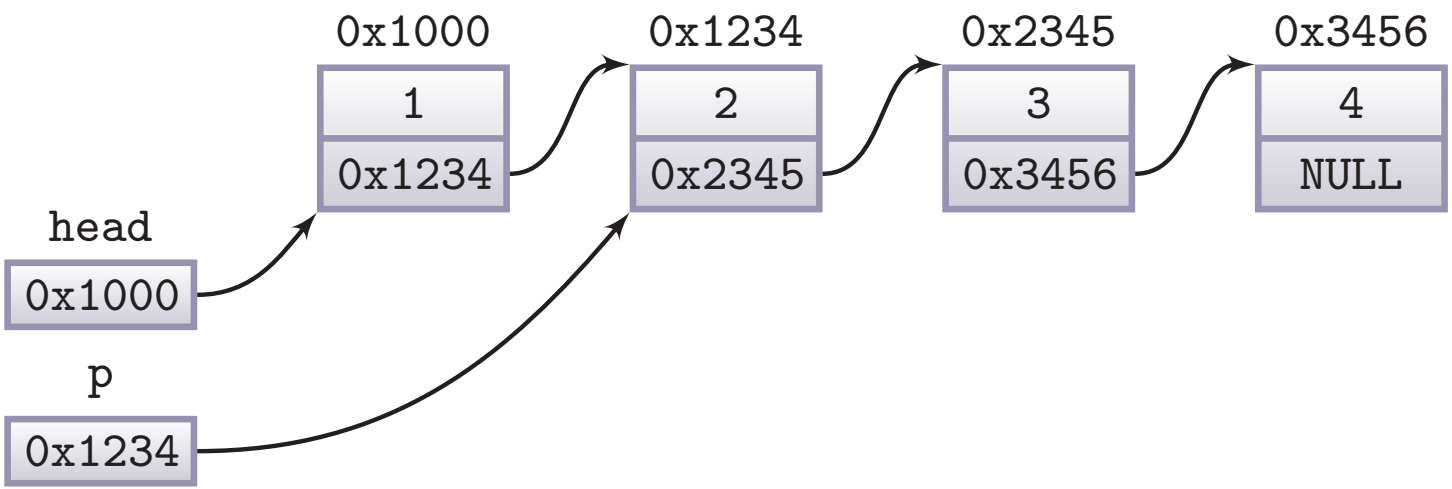

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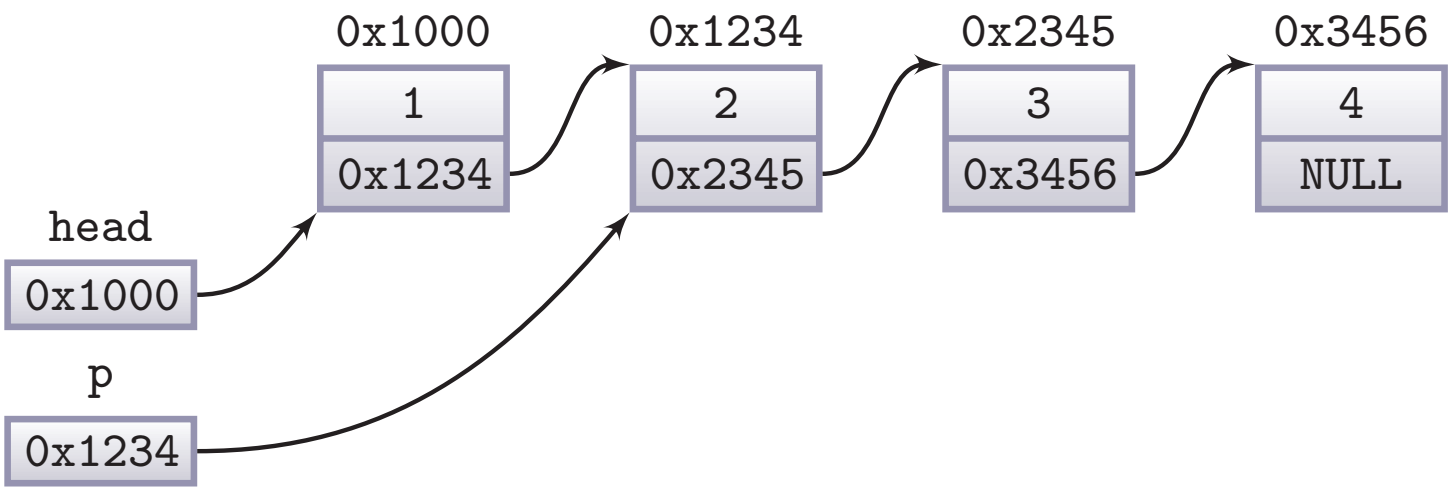

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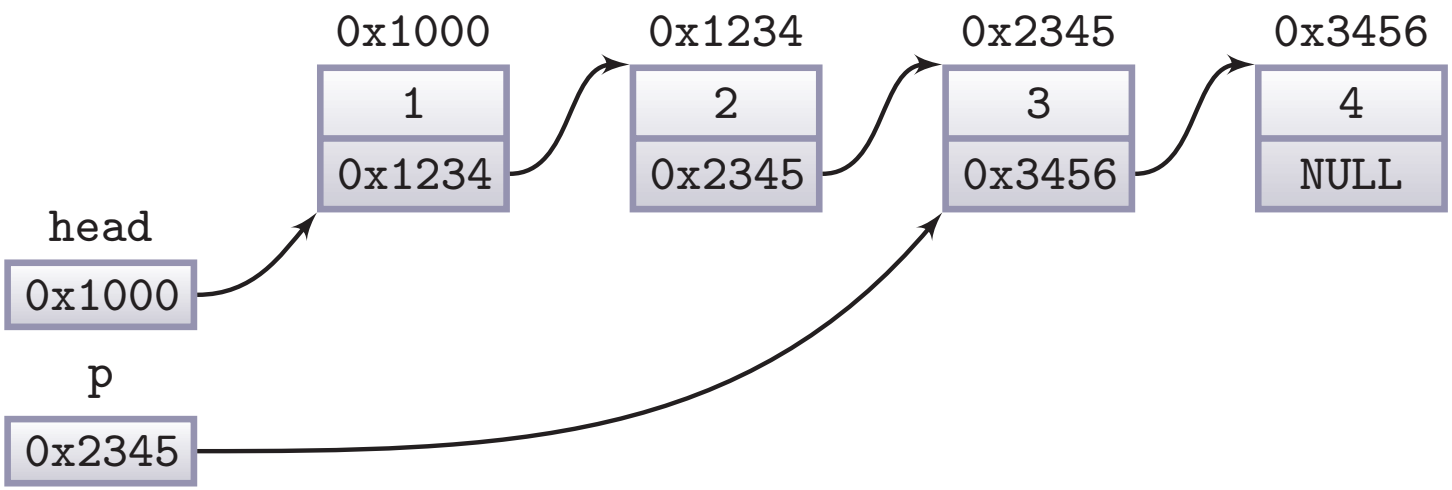

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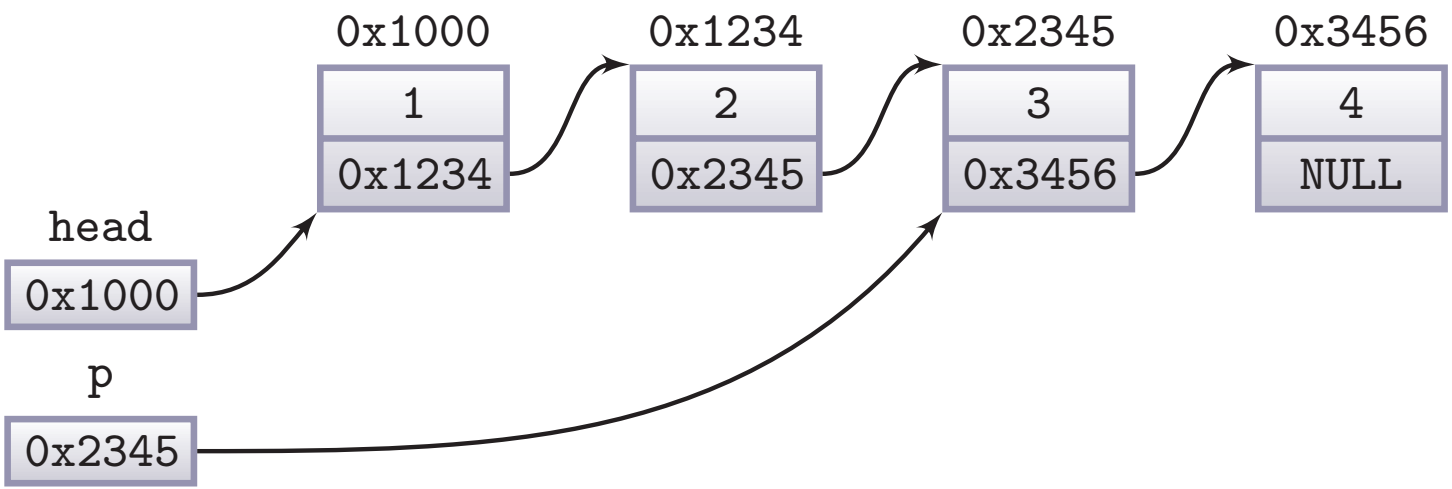

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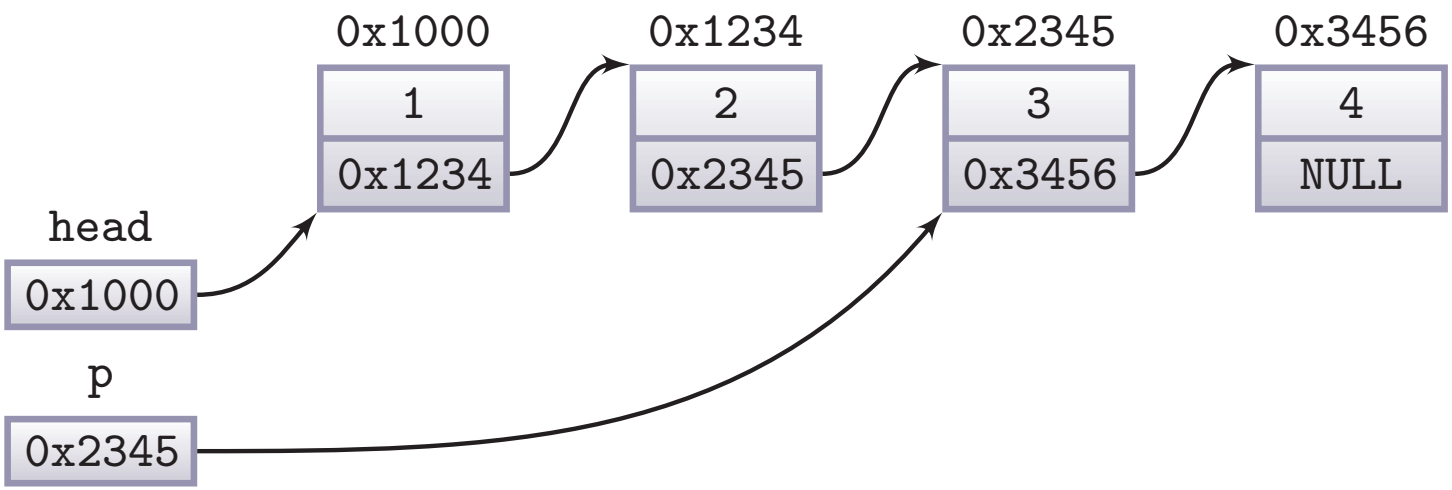

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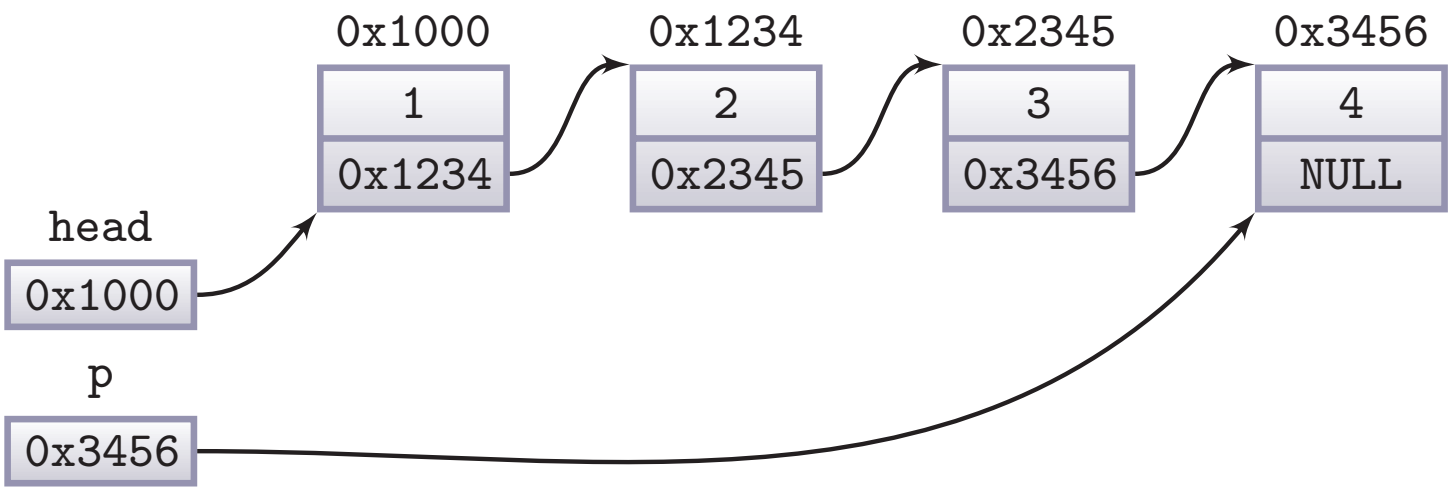

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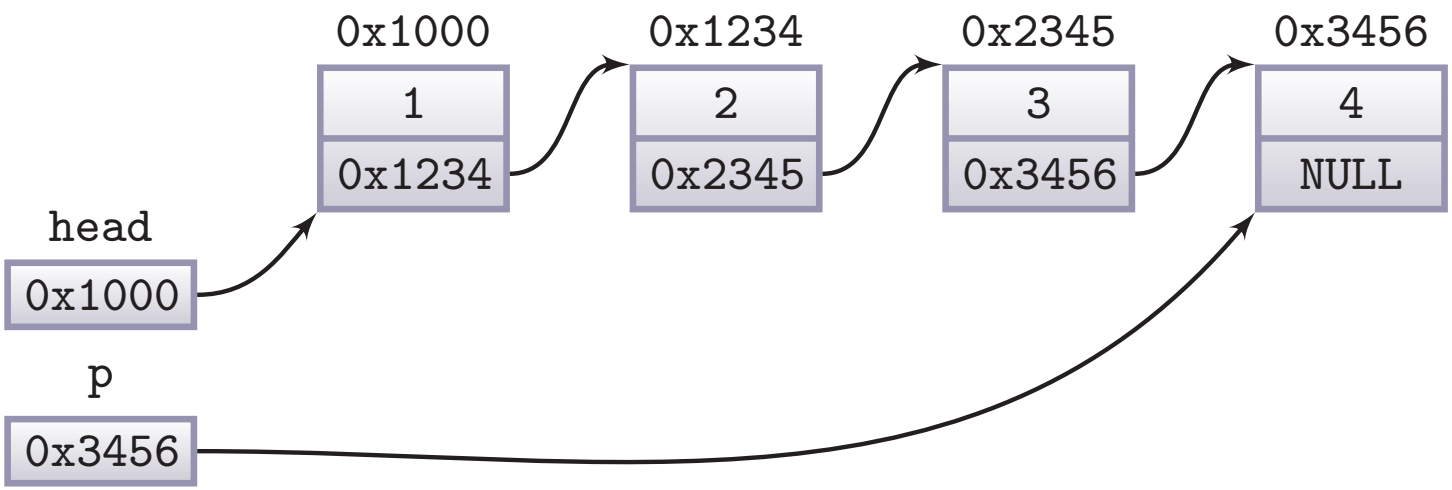

Inserting element to the end of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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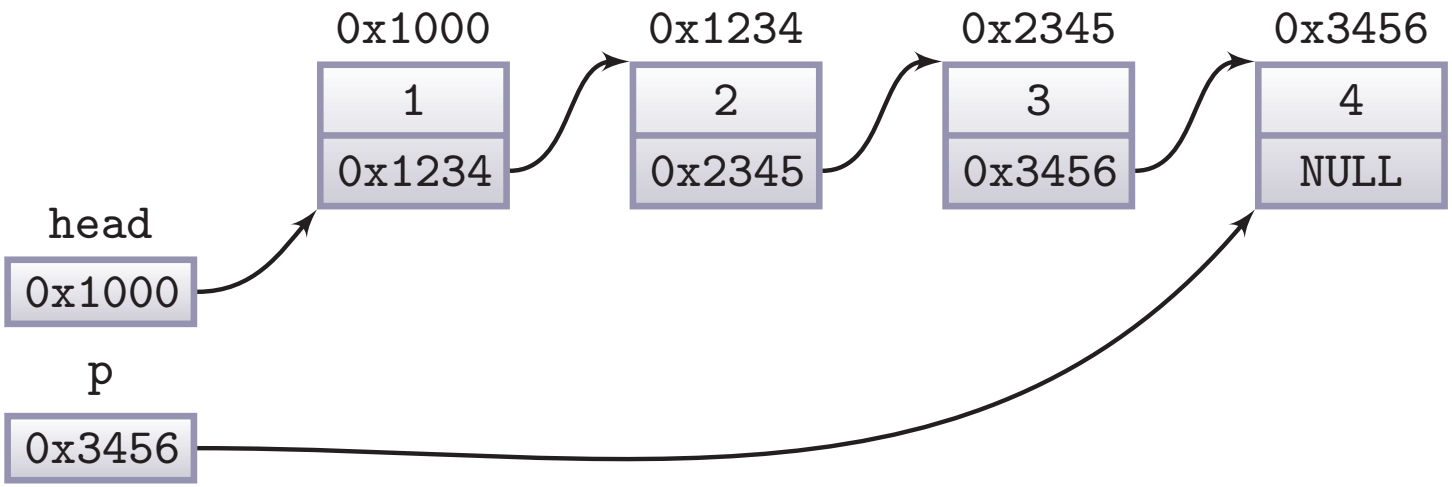

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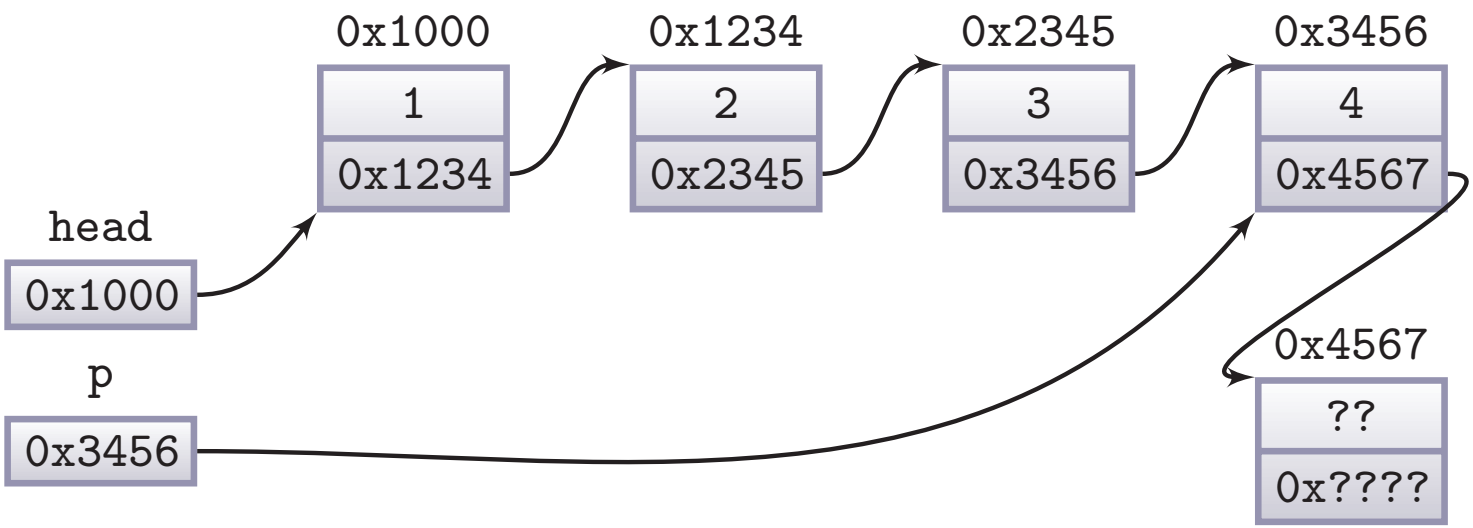

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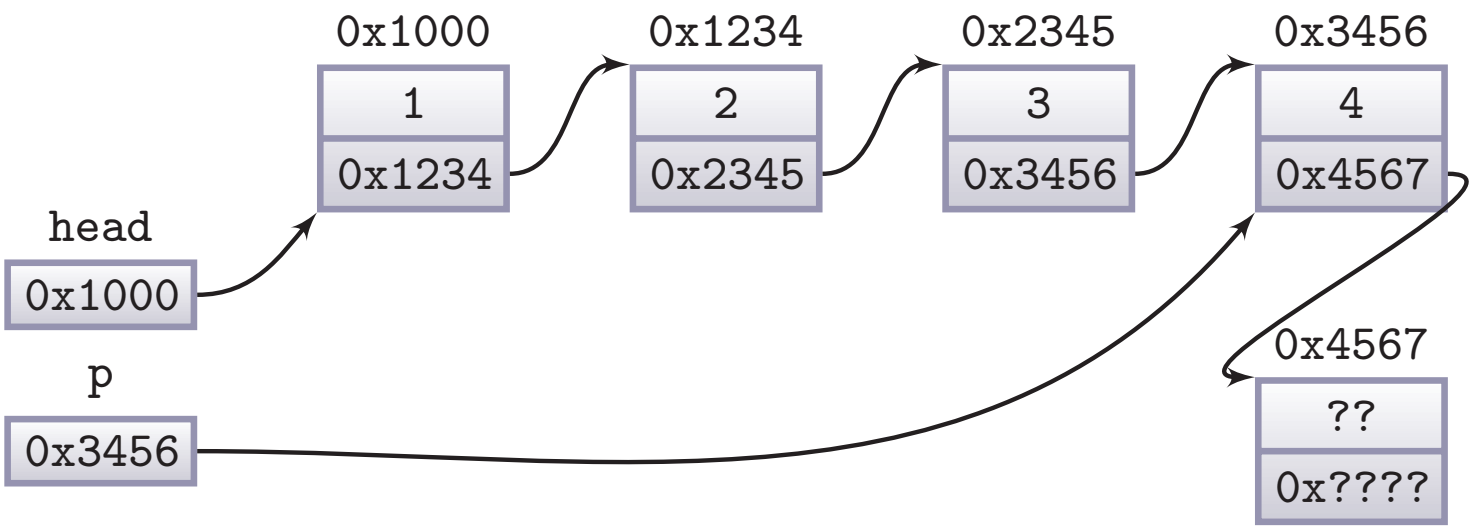

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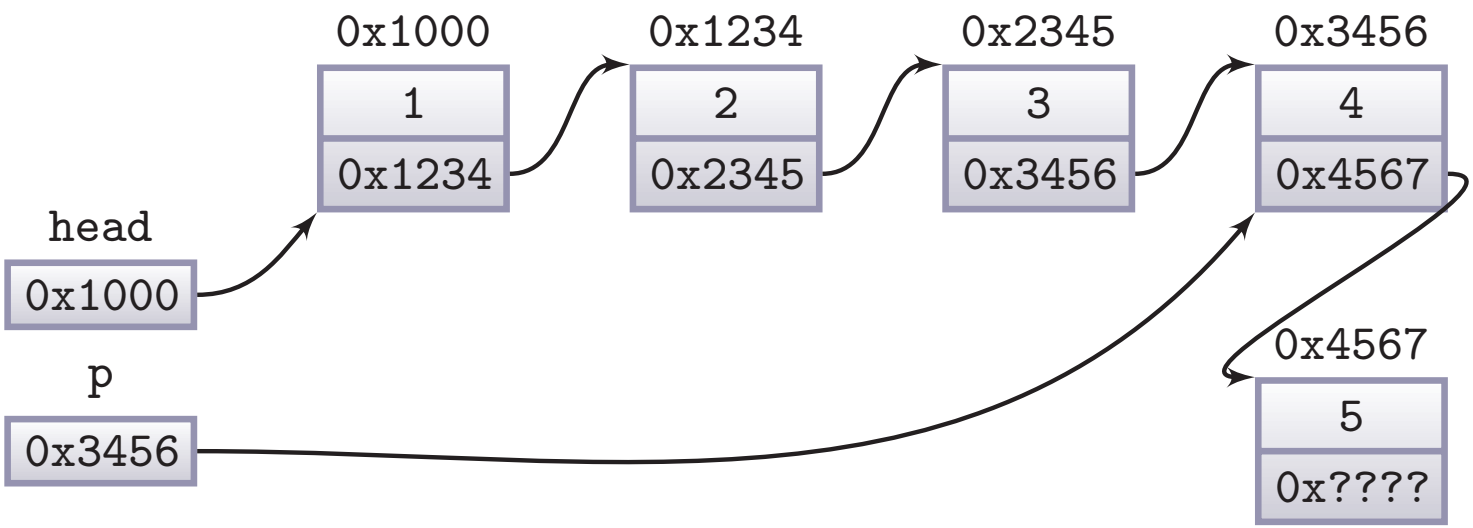

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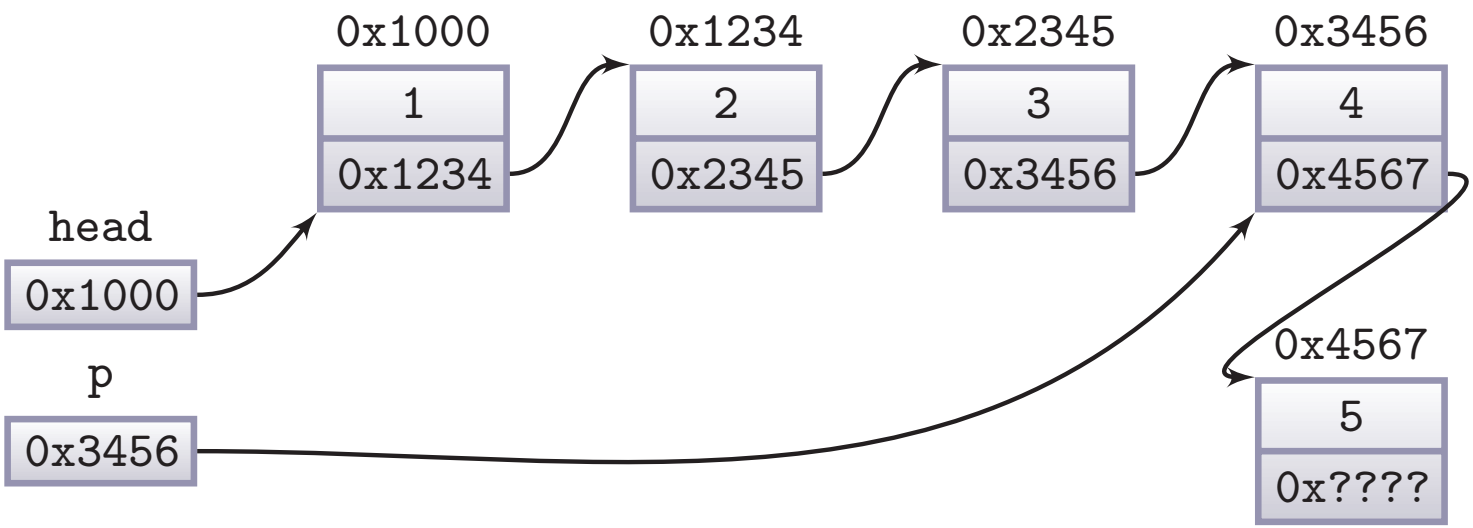

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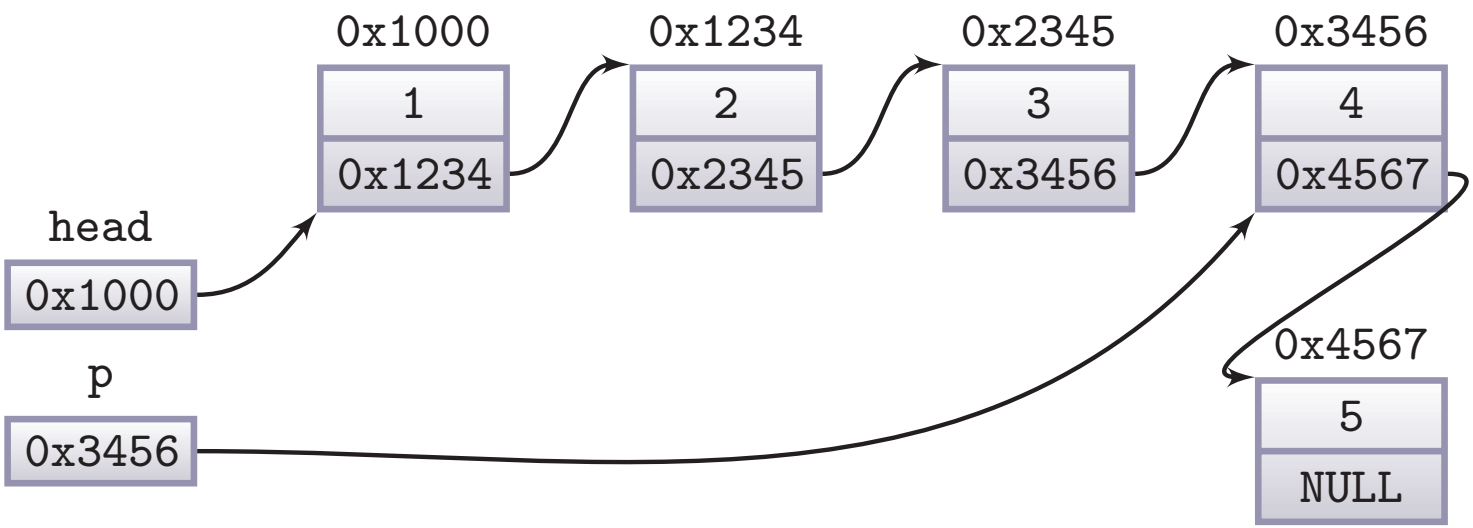

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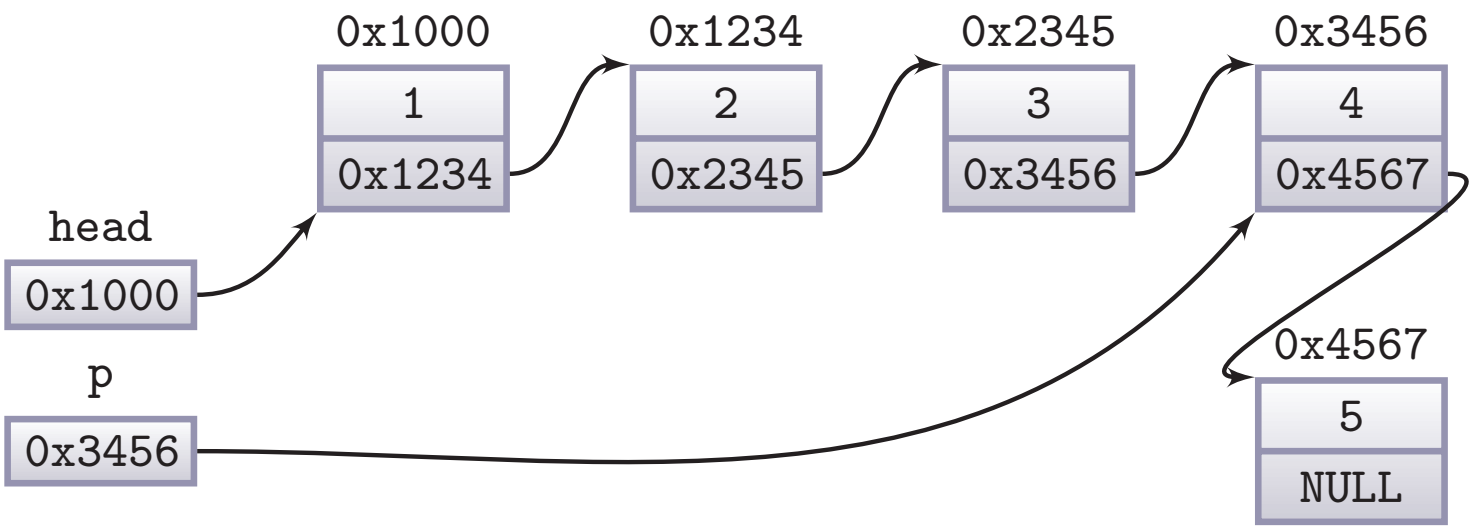

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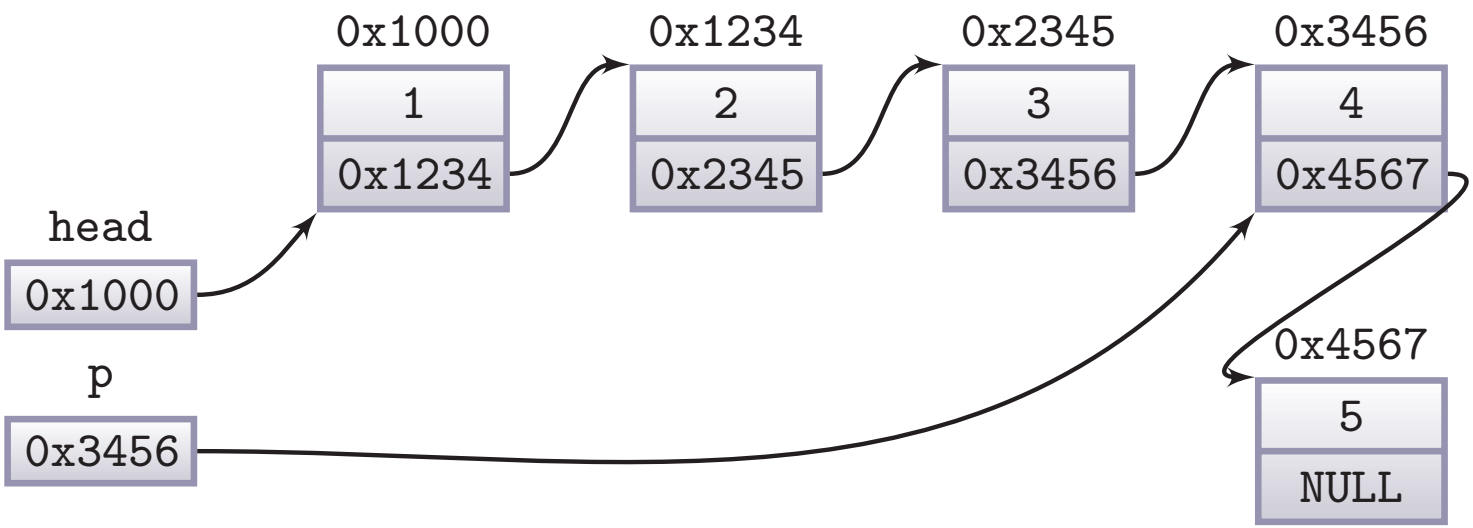

- If the list is empty, checking `p->next != NULL` is not possible, this case must be managed separately!

Inserting element to the end of the list with a function

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  listelem *push_back(listelem *head, int d)
2  {
3    listelem *p;
4
5    if (head == NULL)   /* empty list should be
6                managed separately */
7      return push_front(head, d);
8
9    for (p = head; p->next != NULL; p = p->next);
10   p->next = (listelem*)malloc(sizeof(listelem));
11   p->next->data = d;
12   p->next->next = NULL;
13   return head;
14 }
```

link

```
1  listelem *head = NULL;
2  head = push_back(head, 2);
```

Inserting element into a sorted list

- If we have to traverse and process our data several times, it is worth sorting it
- Arrays:
  - re-locating a single element involves a lot of data movements
  - we fill up the array and order it afterwards

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- The new element must be inserted before the first element that is larger then it
- In the present structure each element "can see" only behind itself, so we cannot insert element before another
- We will use two pointers for traversing the list, one of them will be one step behind (delayed)
- We will insert after the delayed pointer

Inserting element (4) into a sorted list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  q = head;  p = q->next;
2  while (p != NULL && p->data <= data) { /* shortcut */
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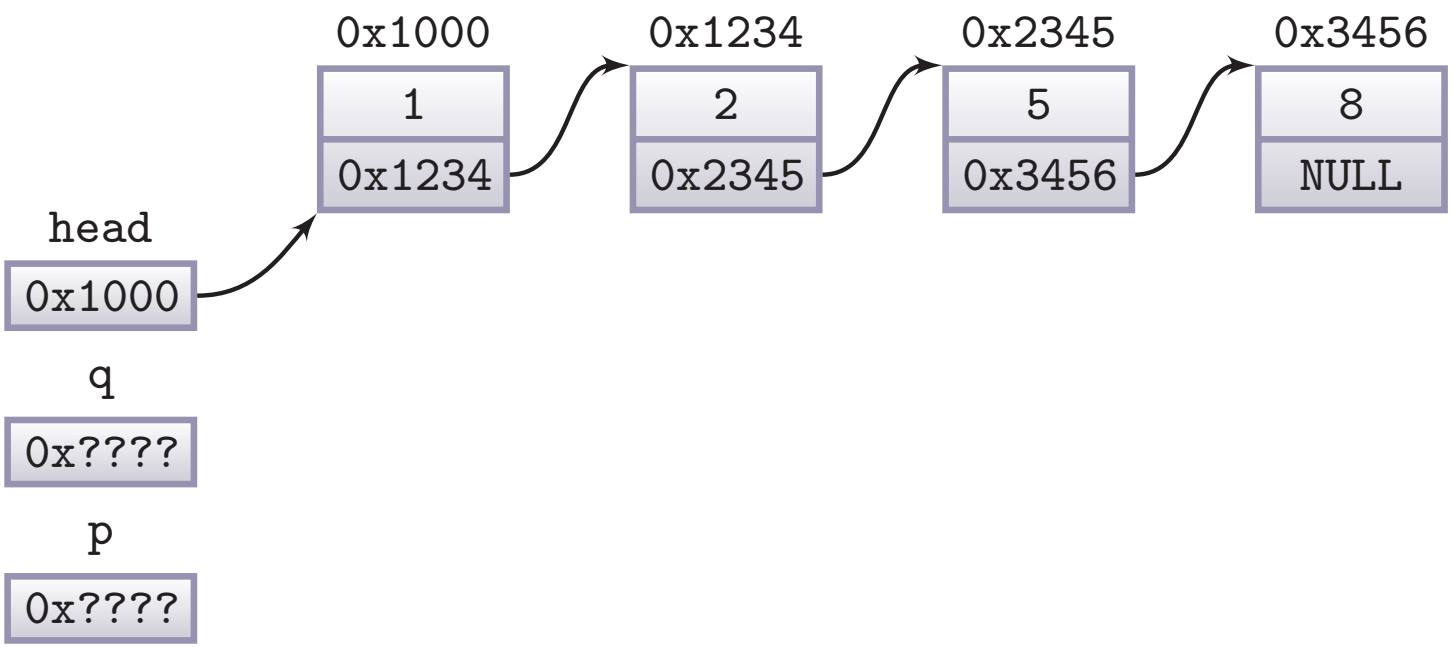

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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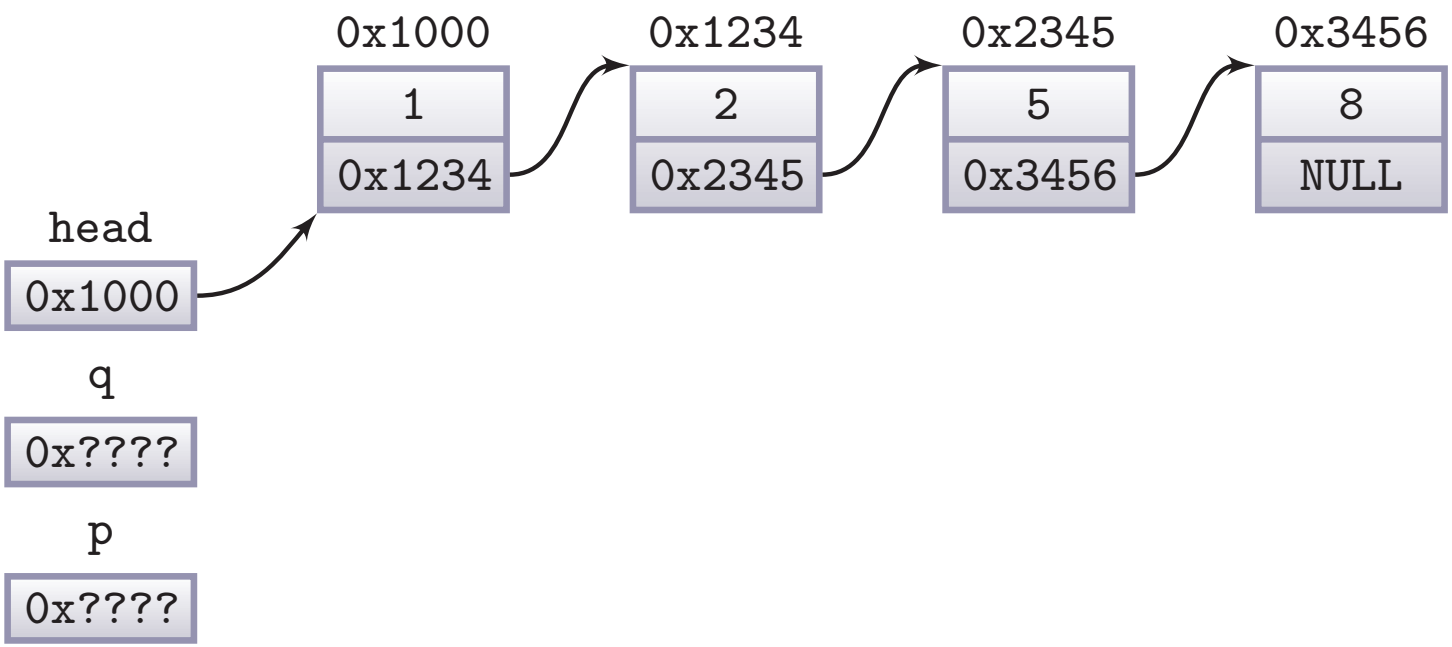

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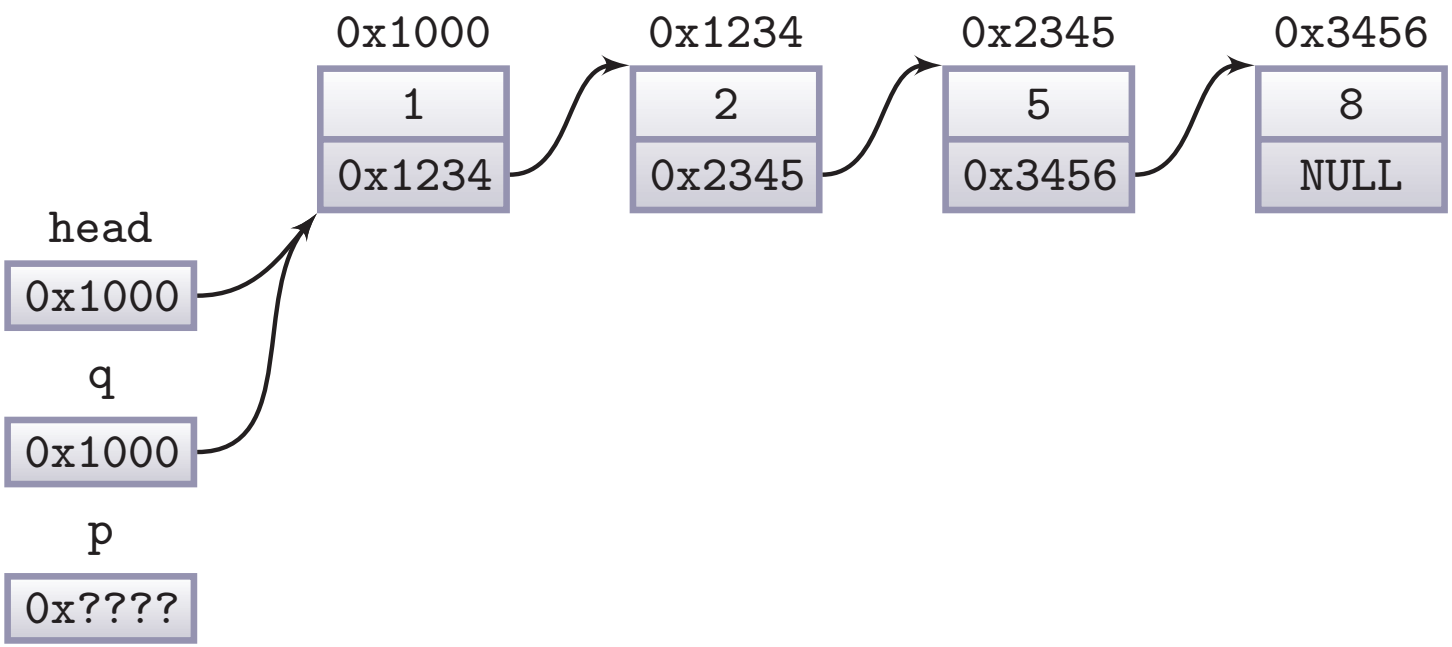

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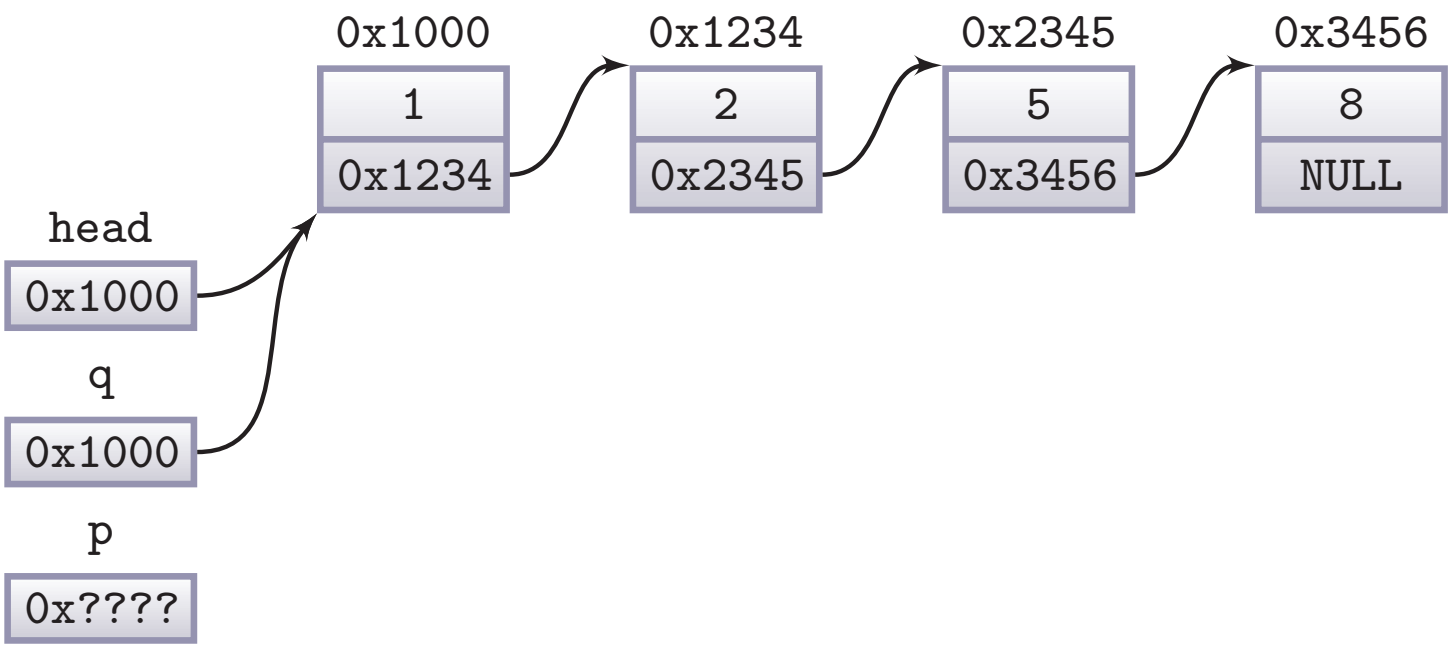

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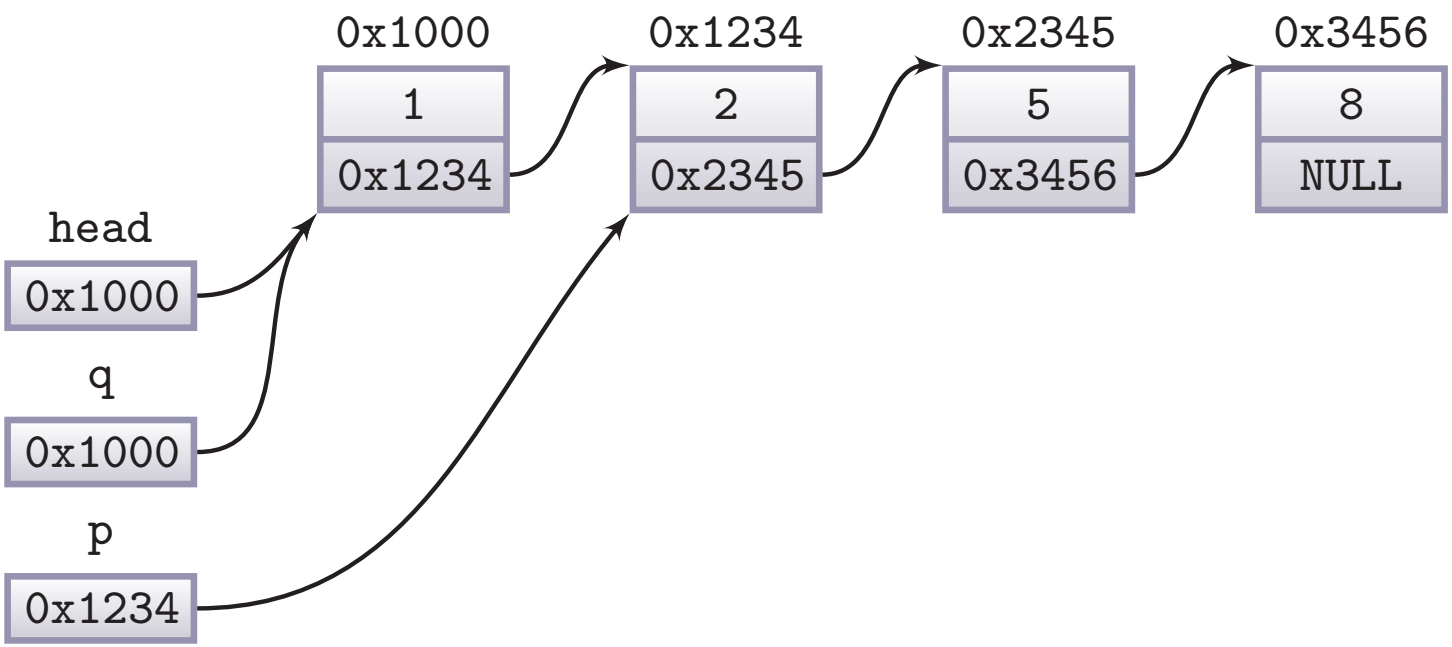

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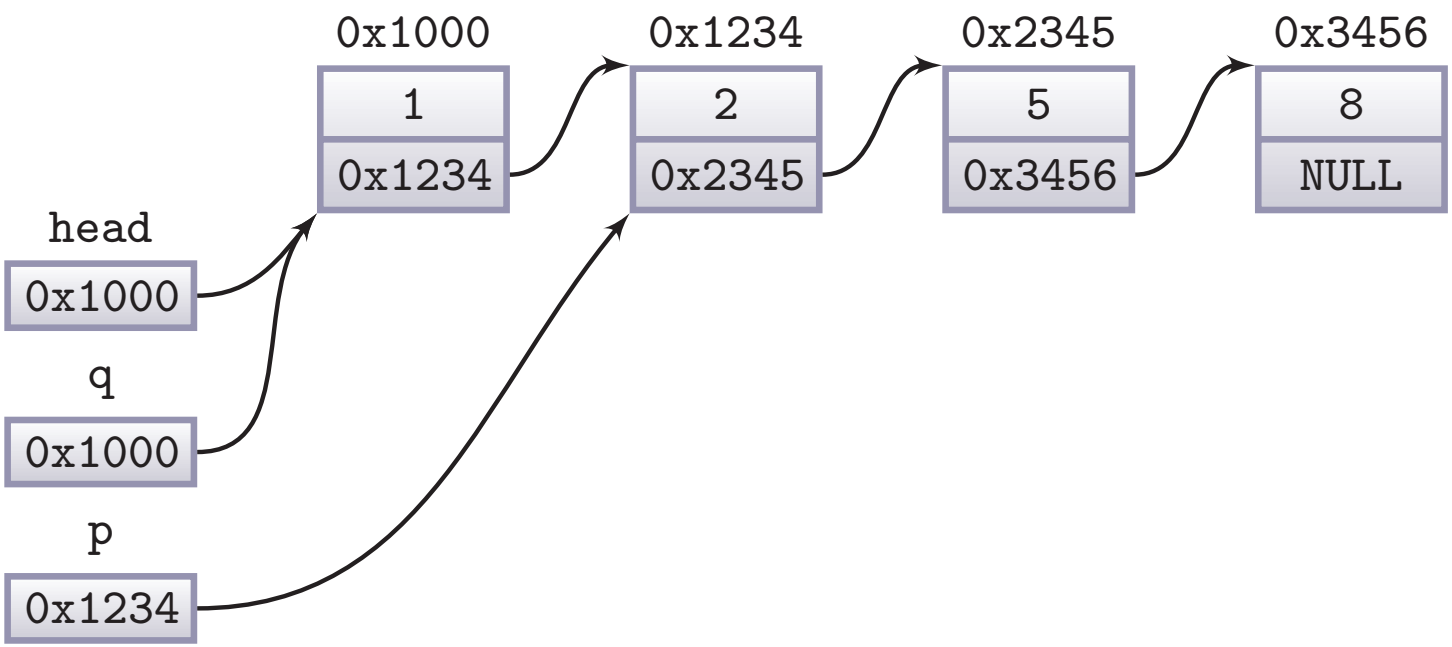

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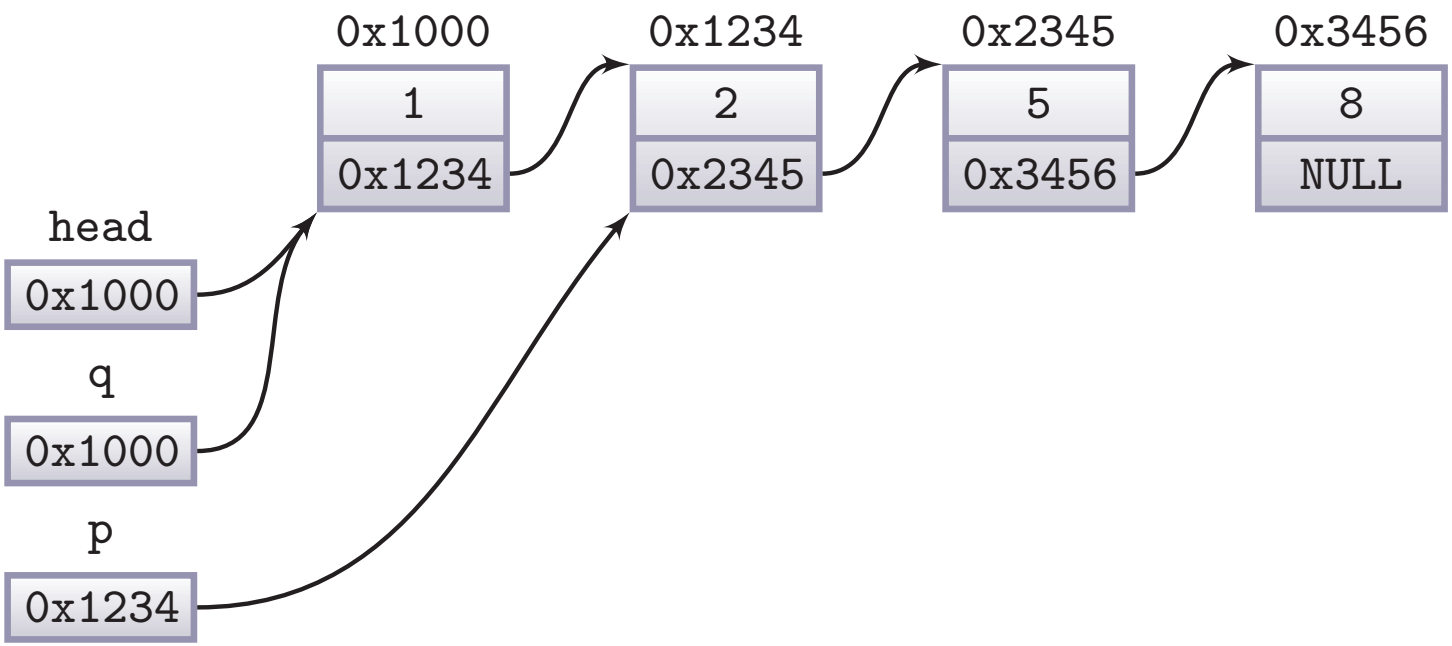

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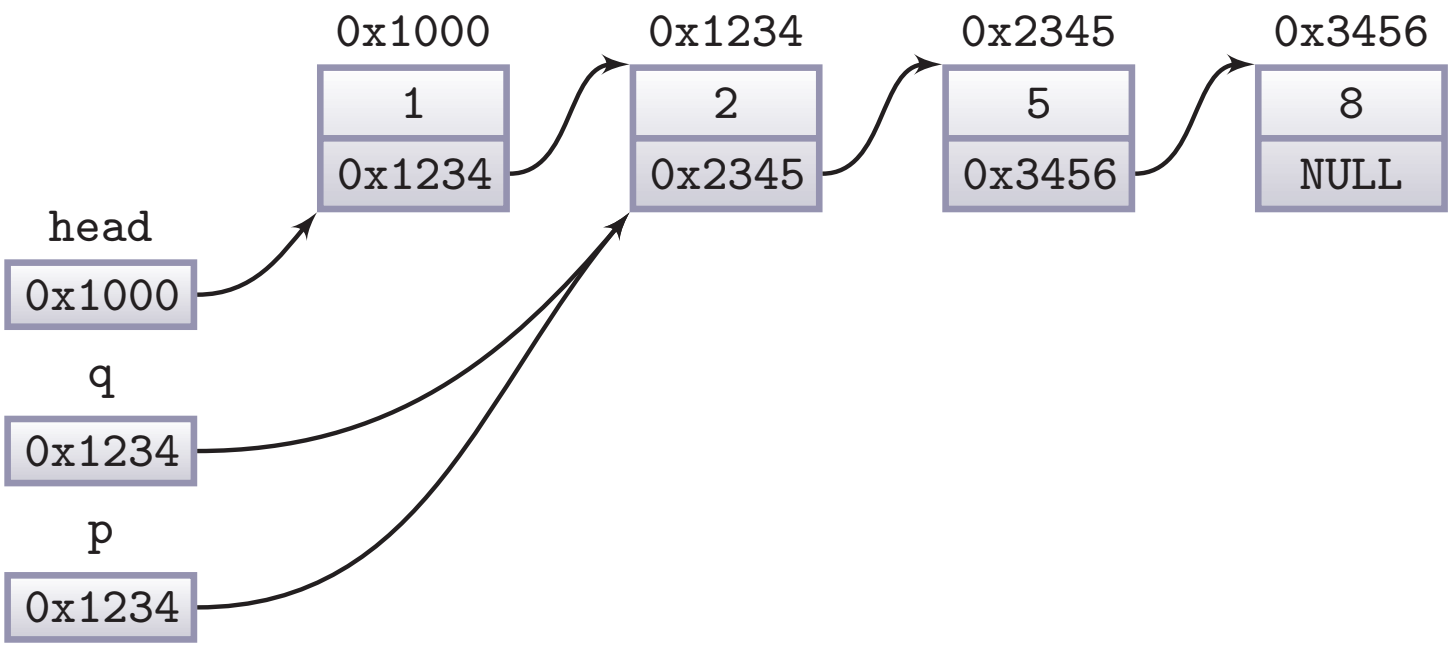

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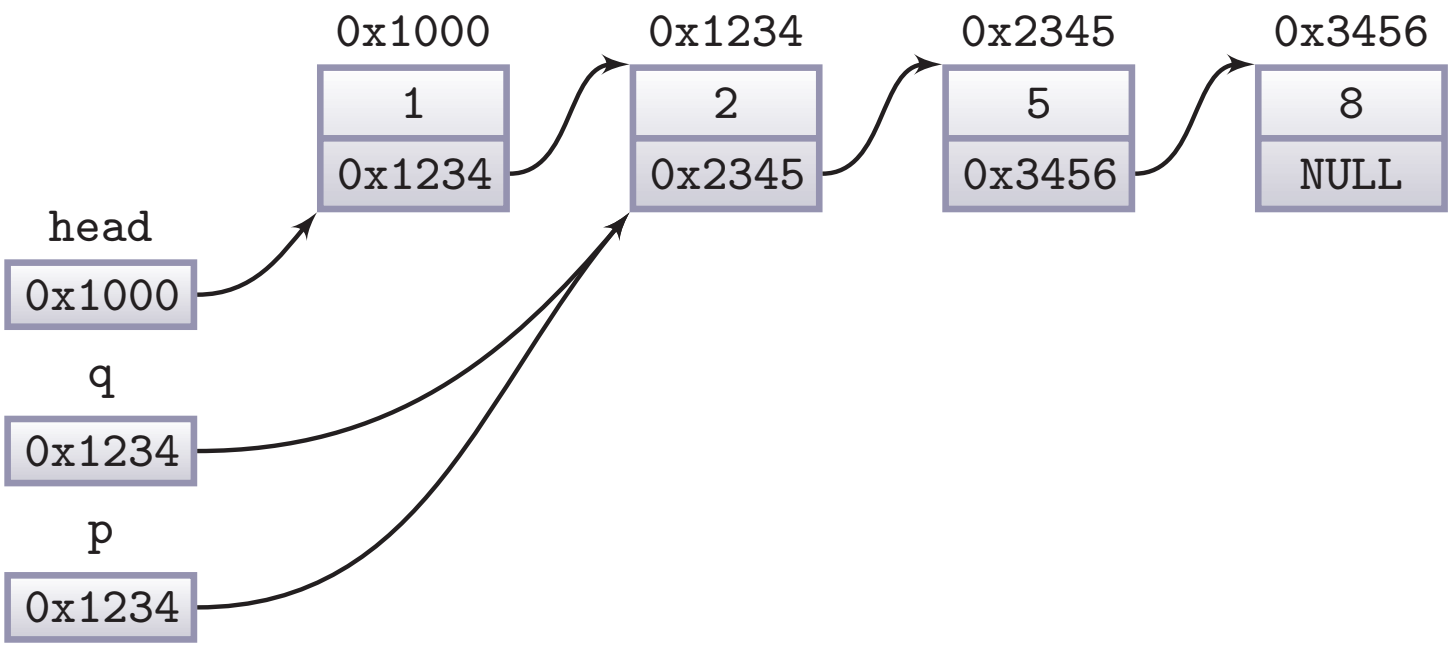

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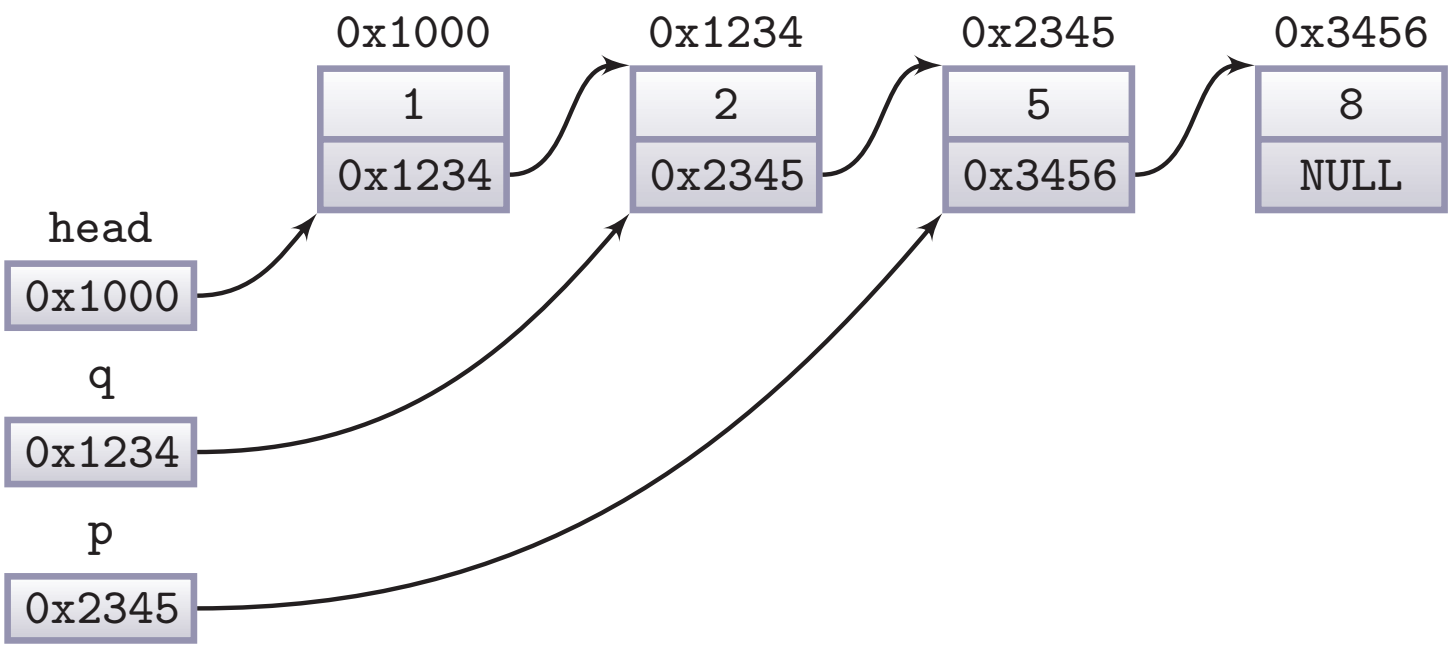

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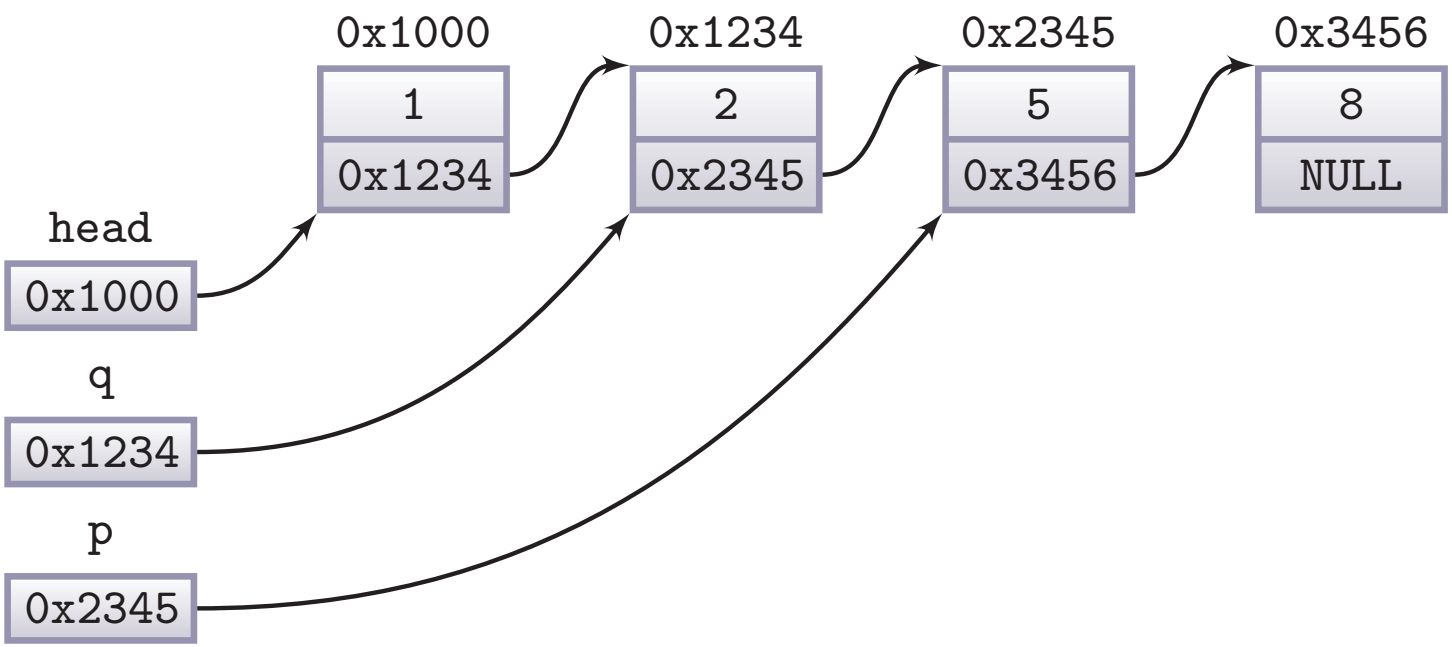

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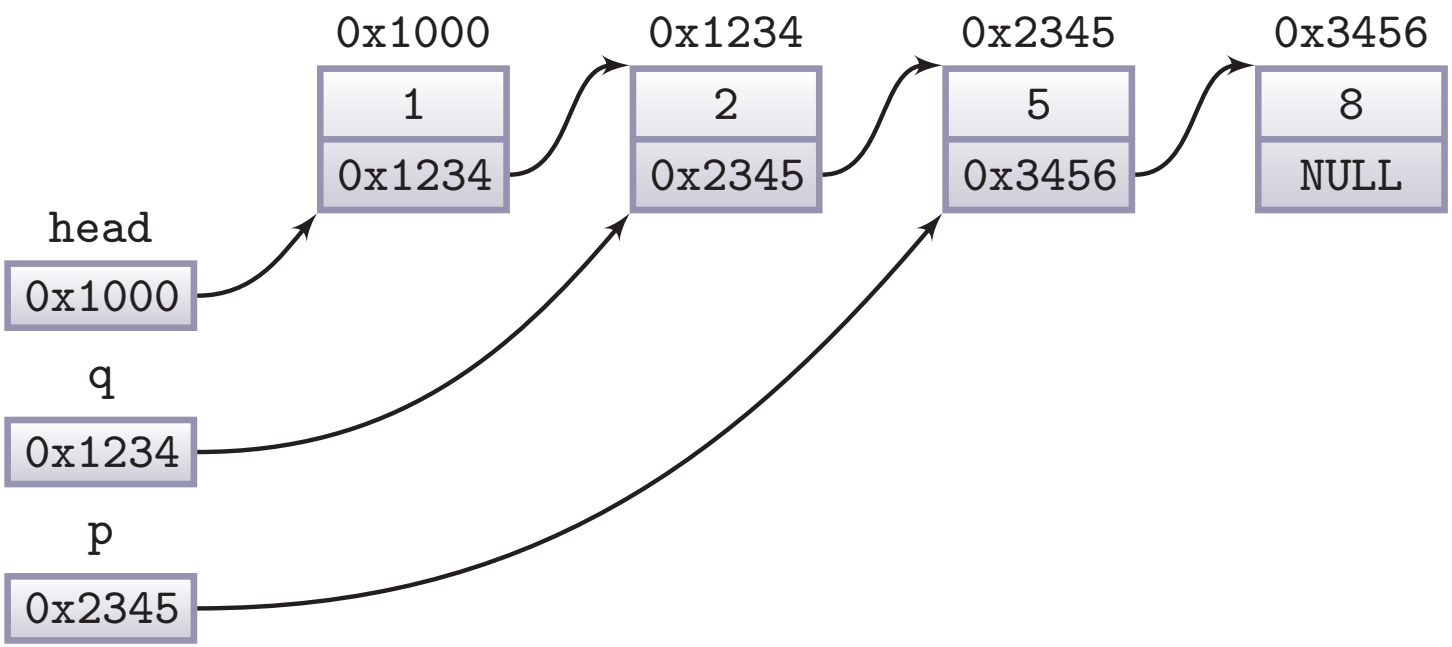

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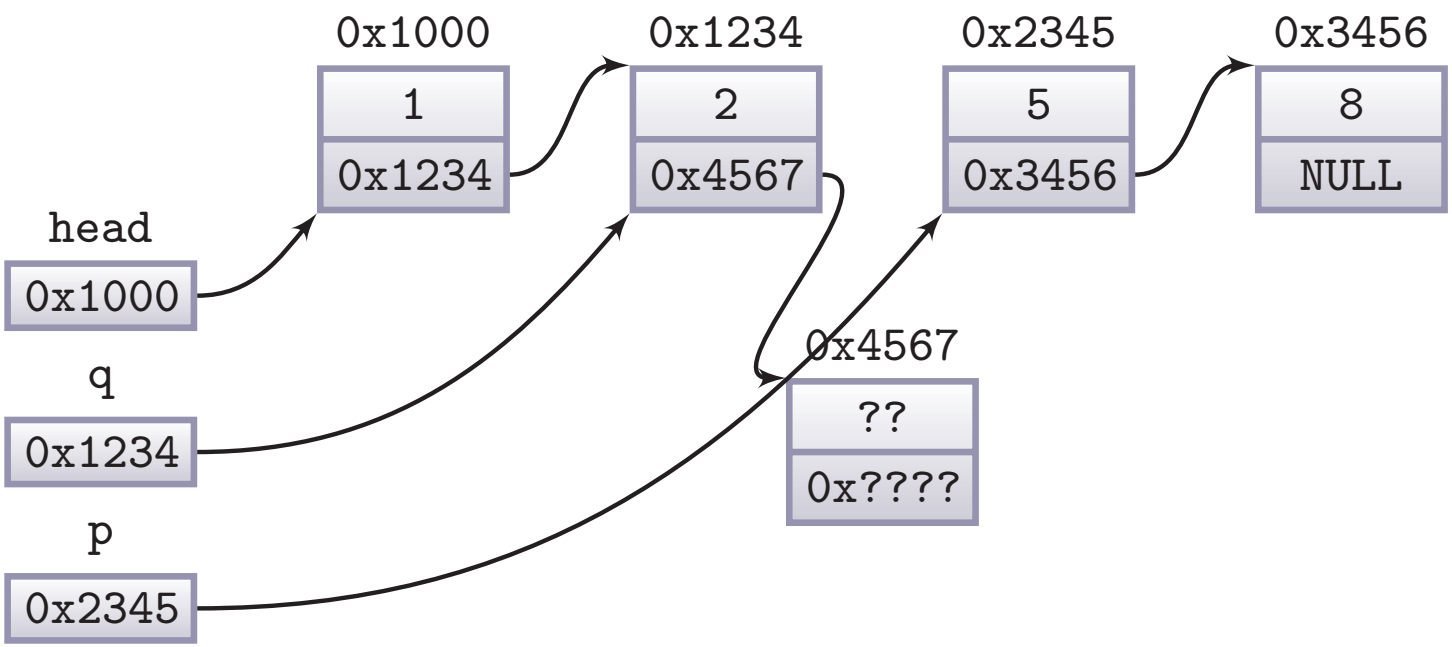

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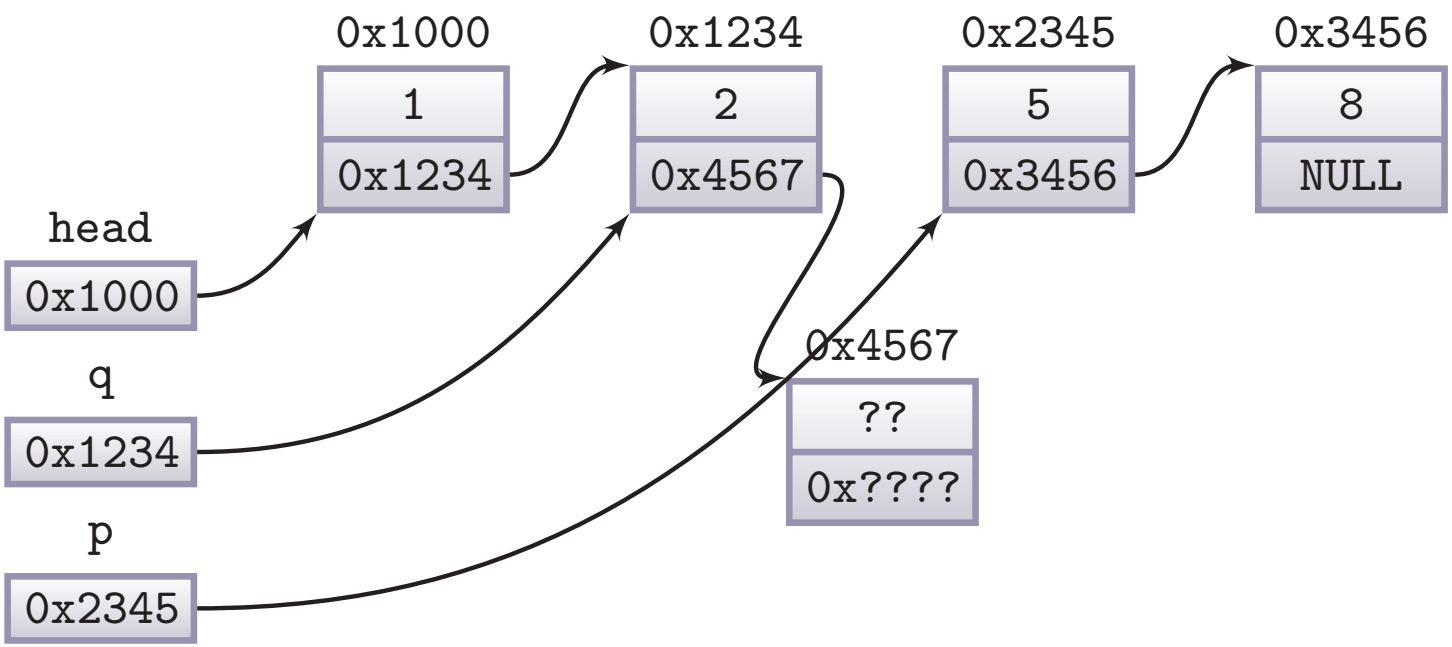

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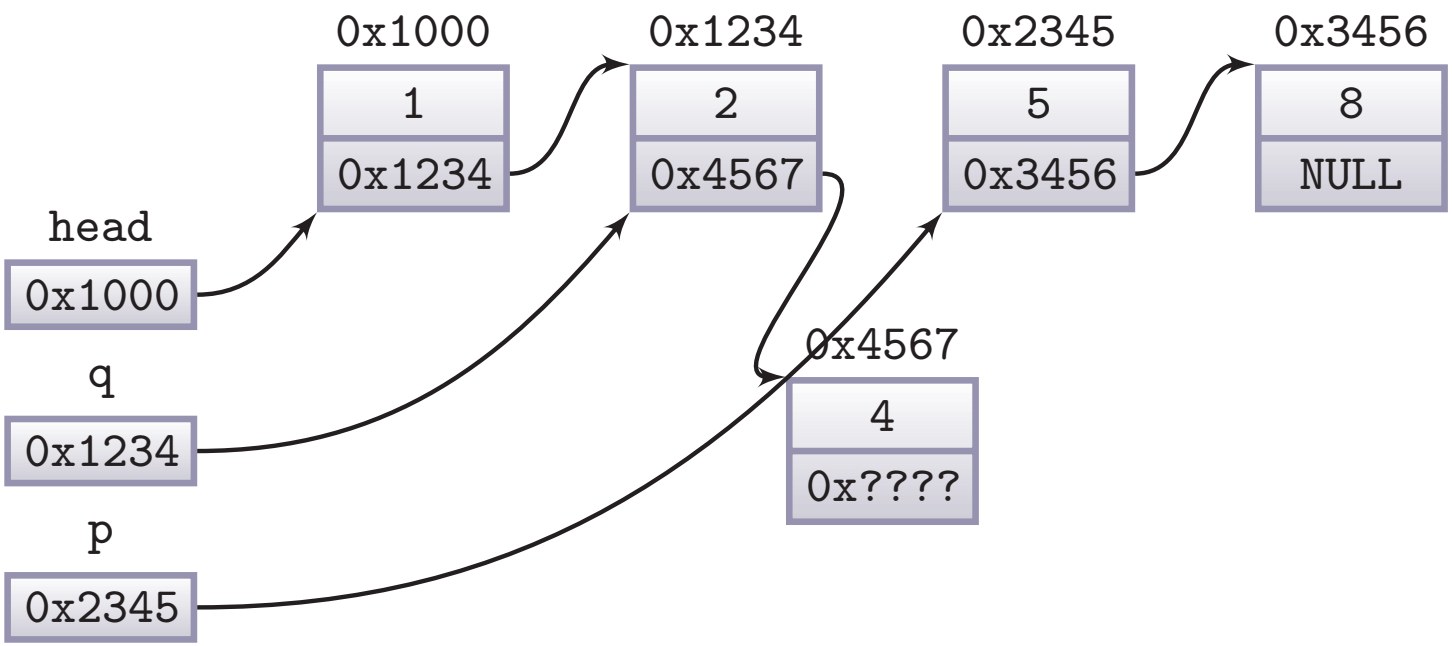

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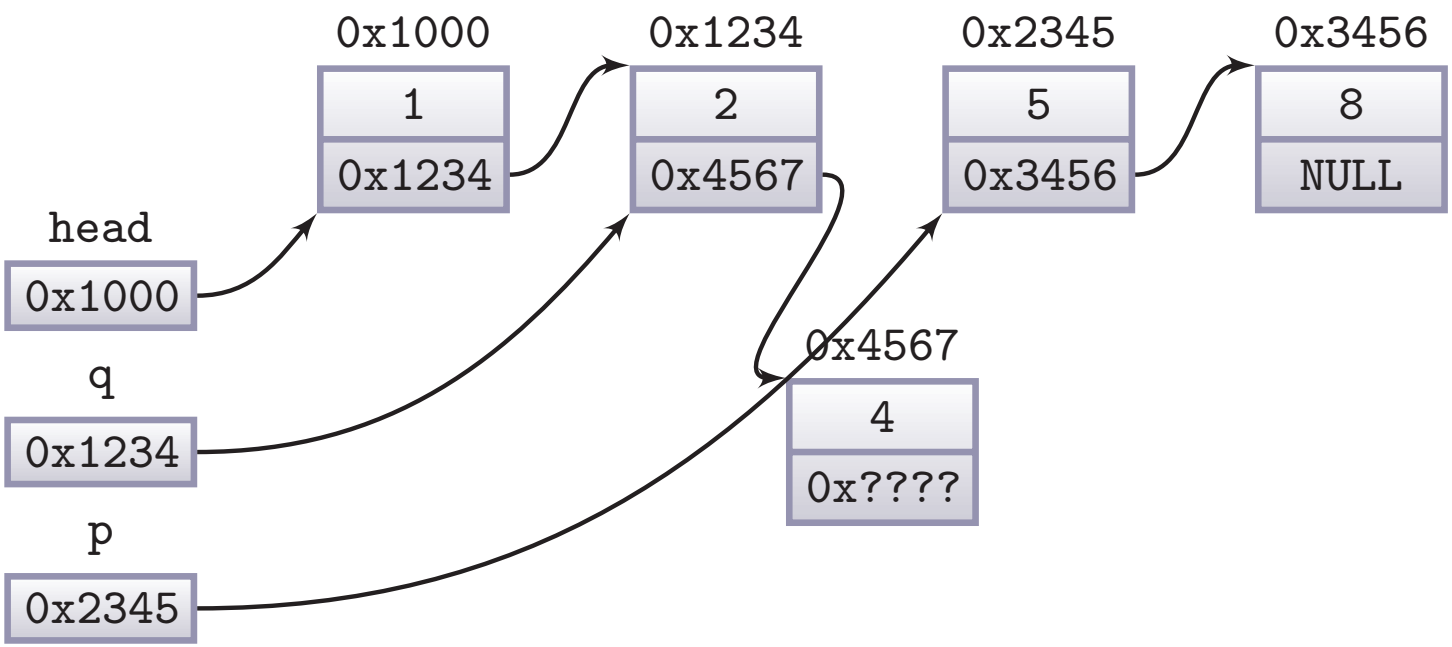

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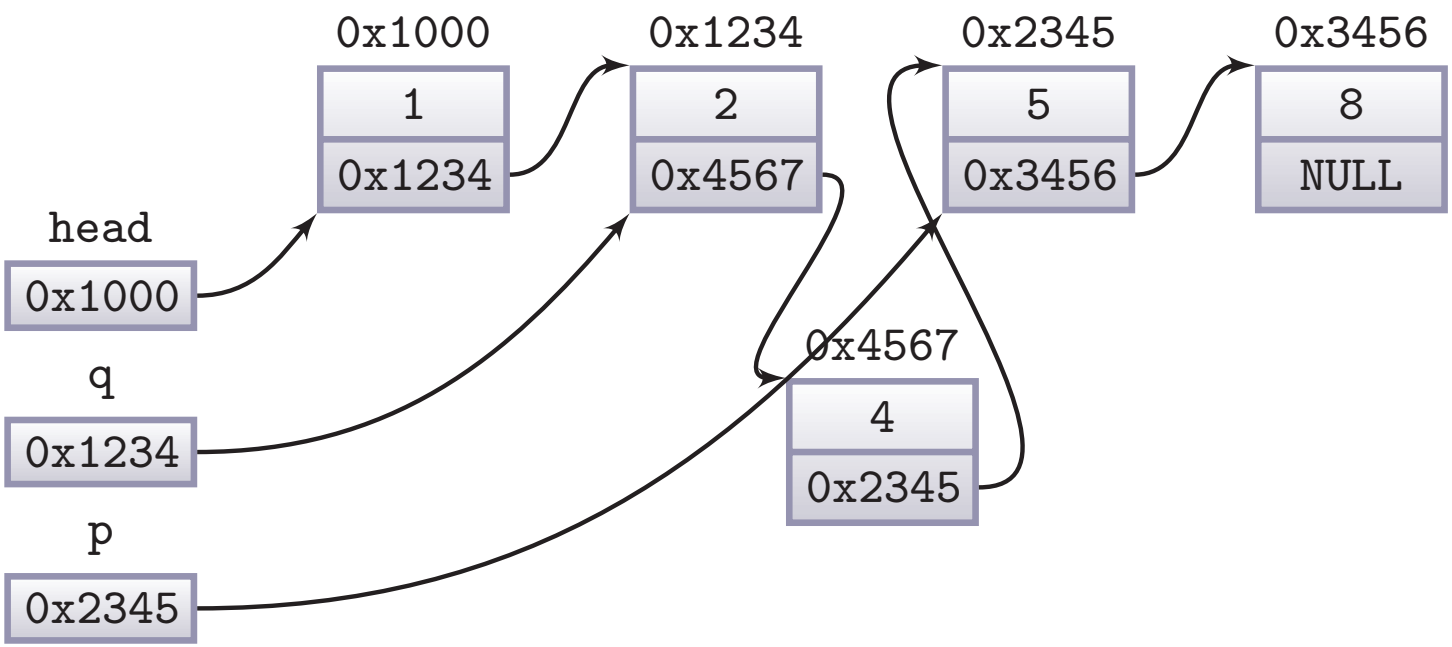

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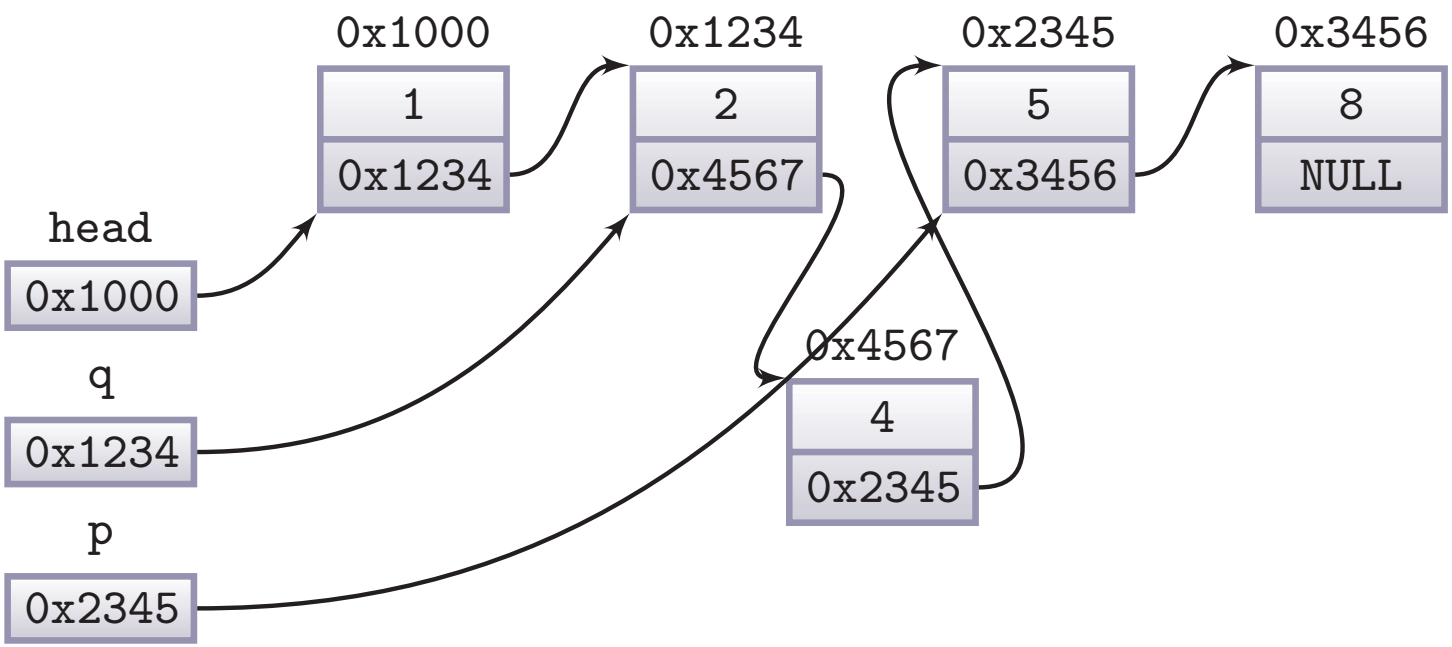


Inserting element into a sorted list with a functio

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

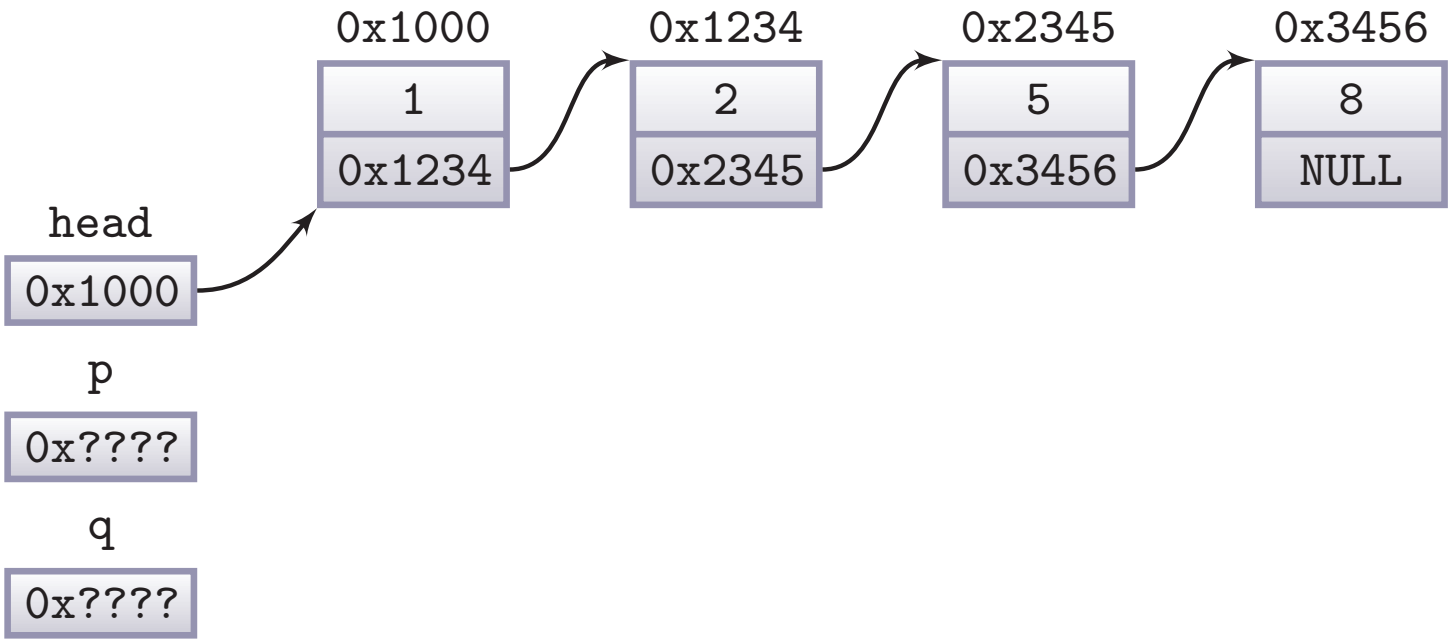
```
1  listelem *insert_sorted(listelem *head, int d)
2  {
3    listelem *p, *q;
4
5    if (head == NULL || head->data > d) /* shortcut */
6      return push_front(head, d);
7
8    q = head;
9    p = q->next;
10   while (p != NULL && p->data <= d) /* shortcut */ {
11     q = p; p = p->next;
12   }
13   q->next = (listelem*)malloc(sizeof(listelem));
14   q->next->data = d;
15   q->next->next = p;
16   return head;
17 }
```

link

Inserting element (4) into a sorted list by replacement

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

- The delayed pointer can be saved (omitted), if we insert behind the selected element, and after that we replace the data.



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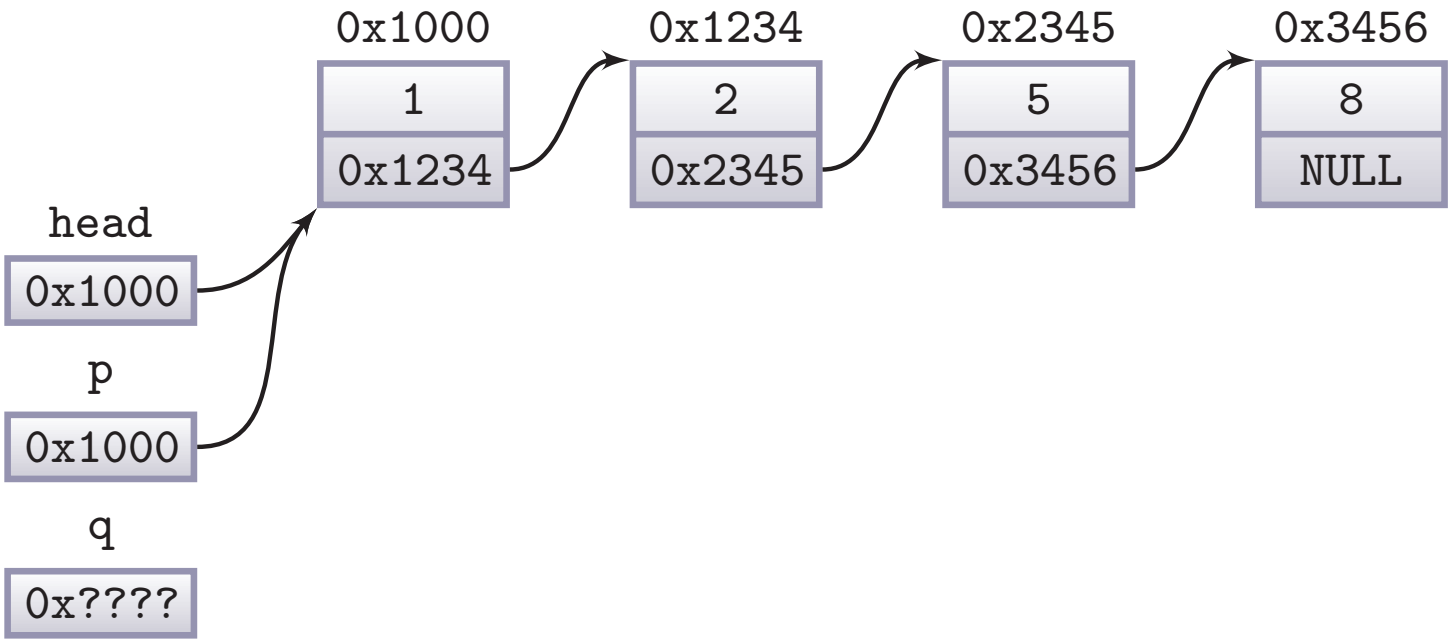

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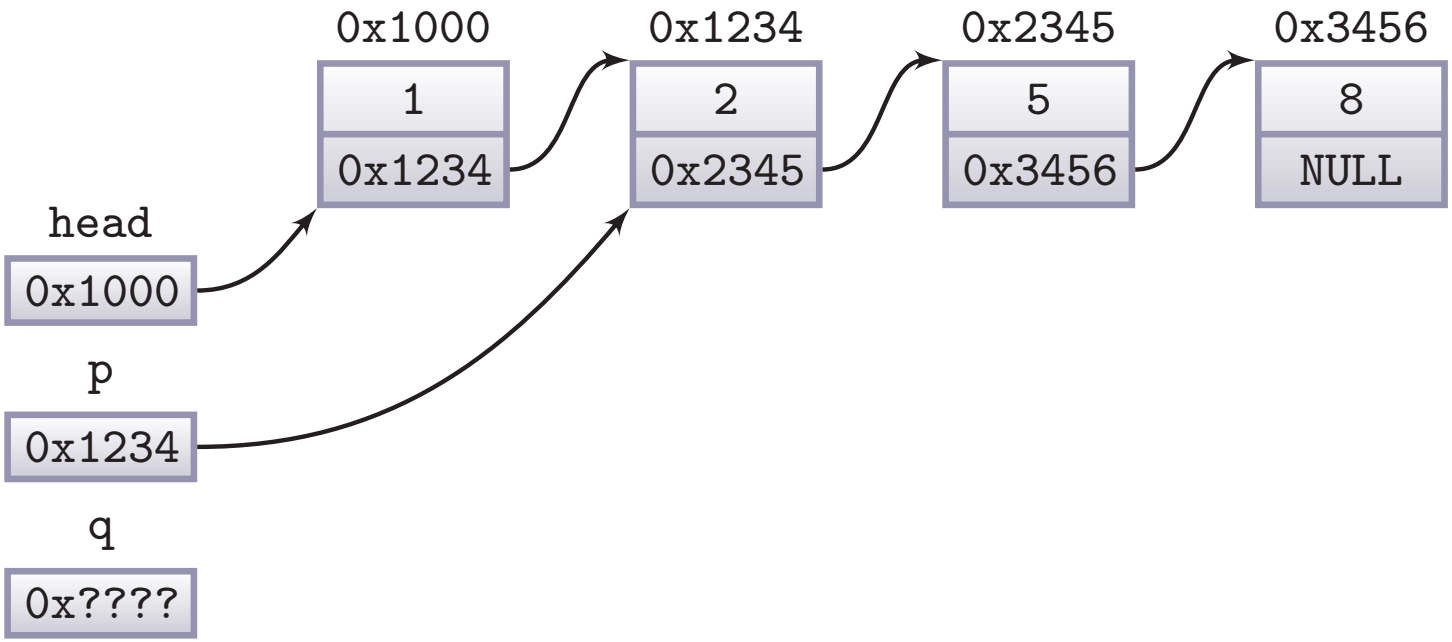

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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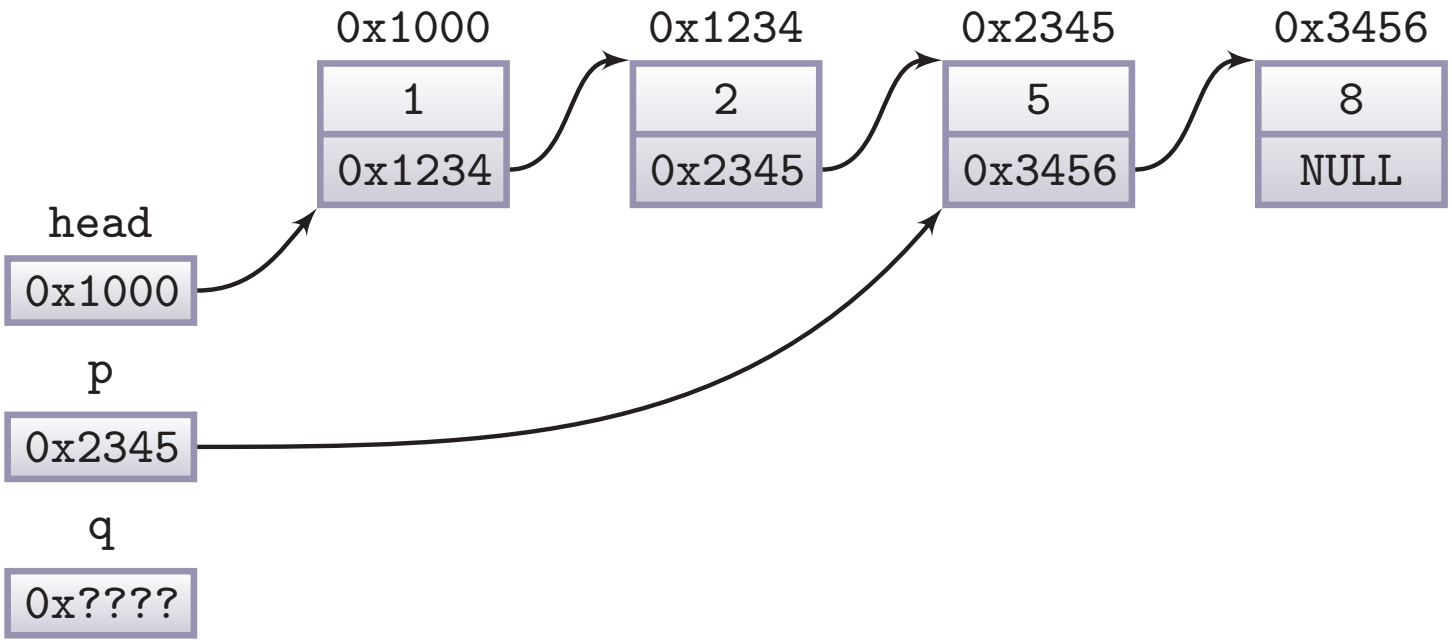

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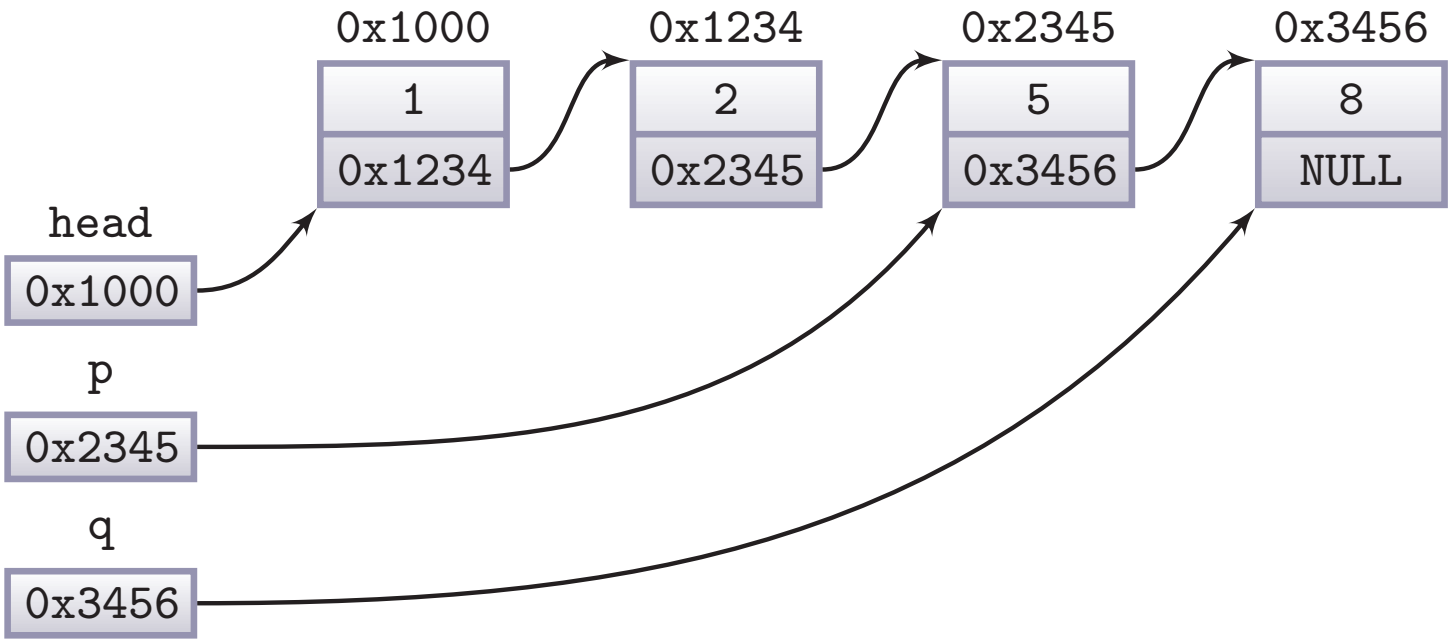

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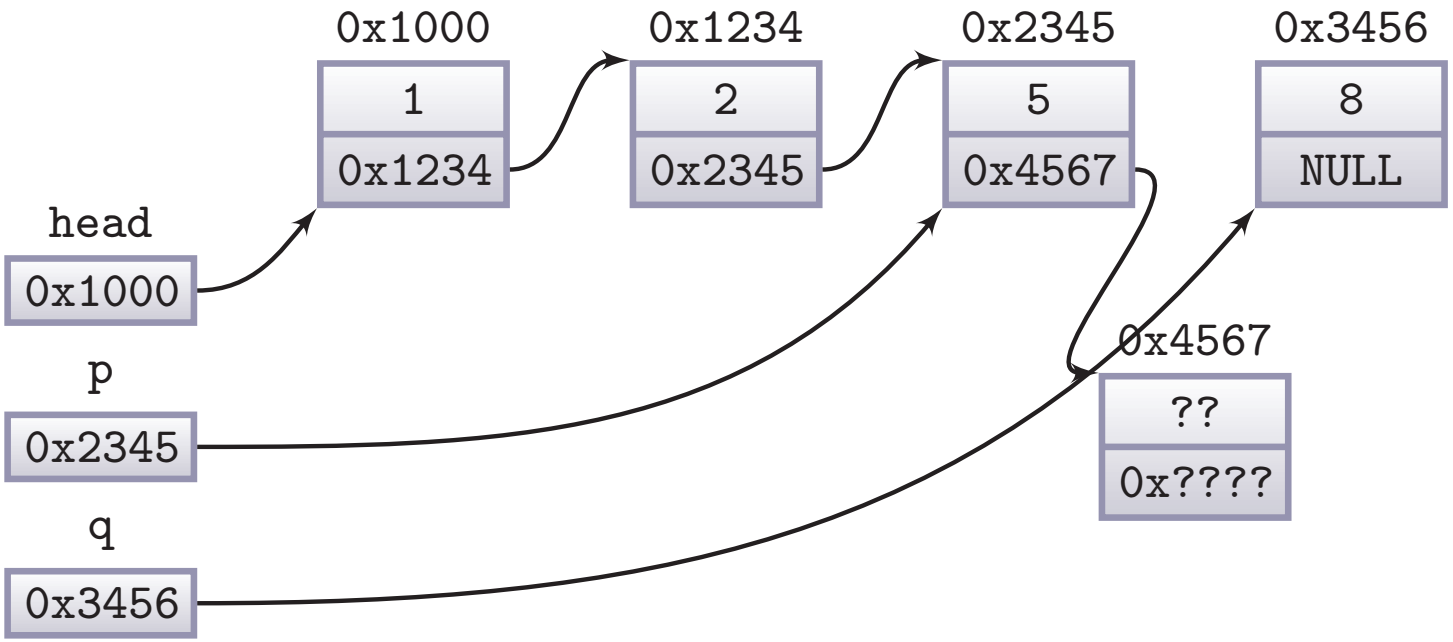

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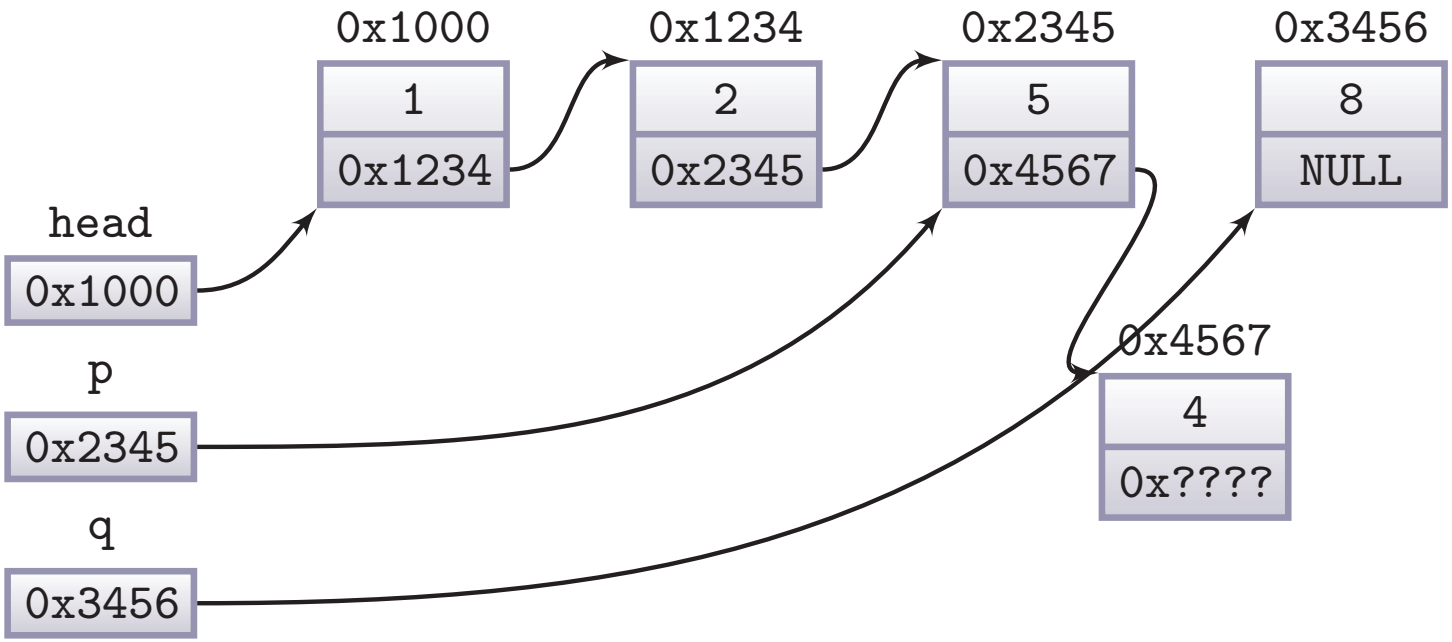

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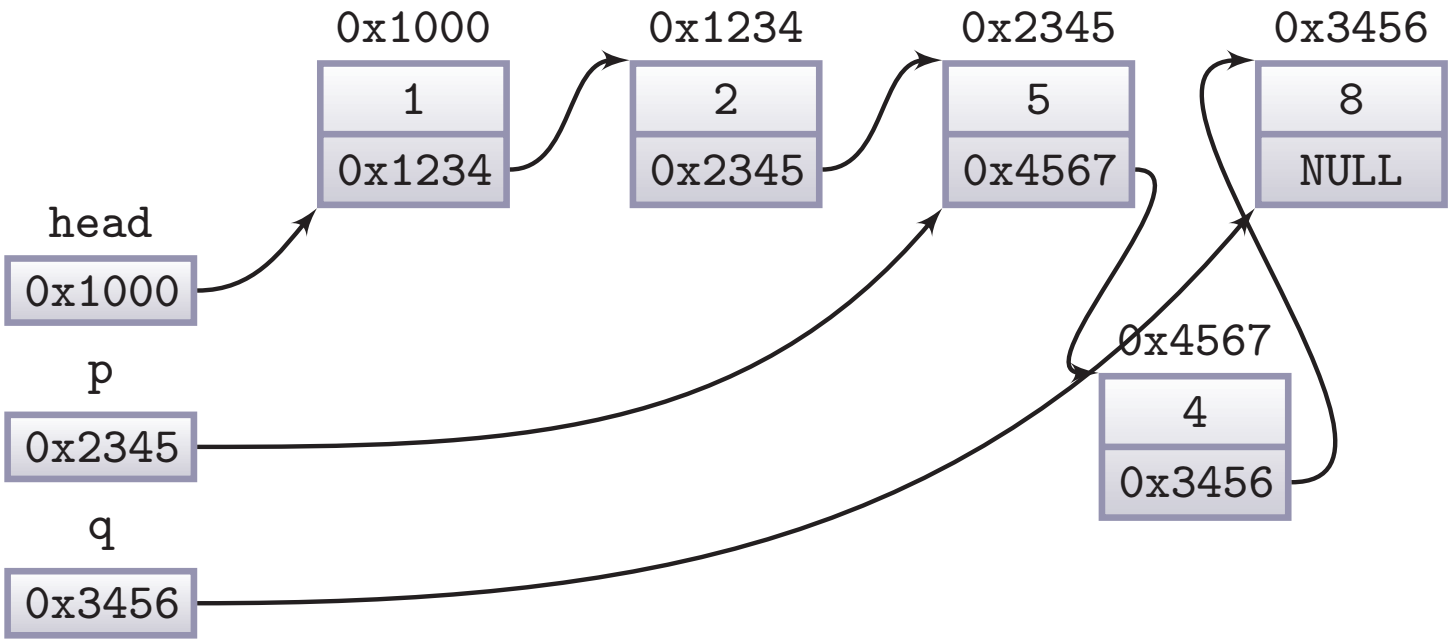

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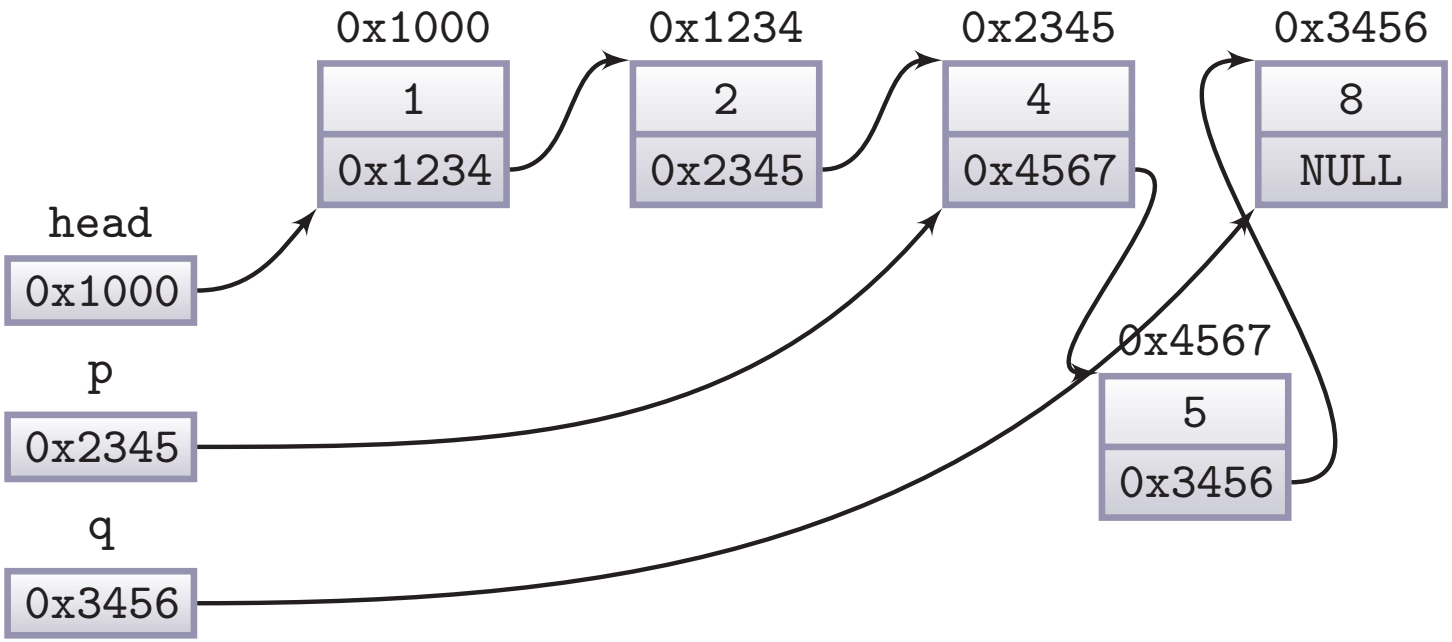

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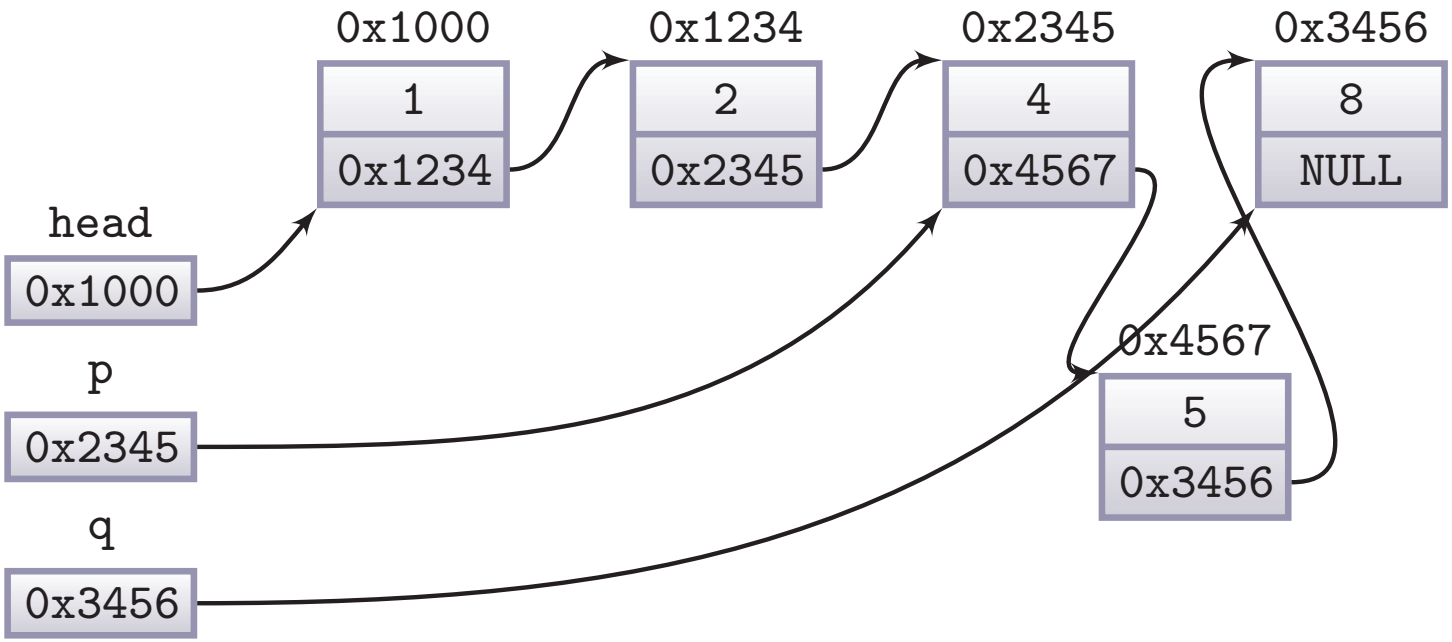

- This algorithm can be used only if we may modify the existing part of the list – others do not refer to it. But in many times this is not like that!

Deleting element from the end of the list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

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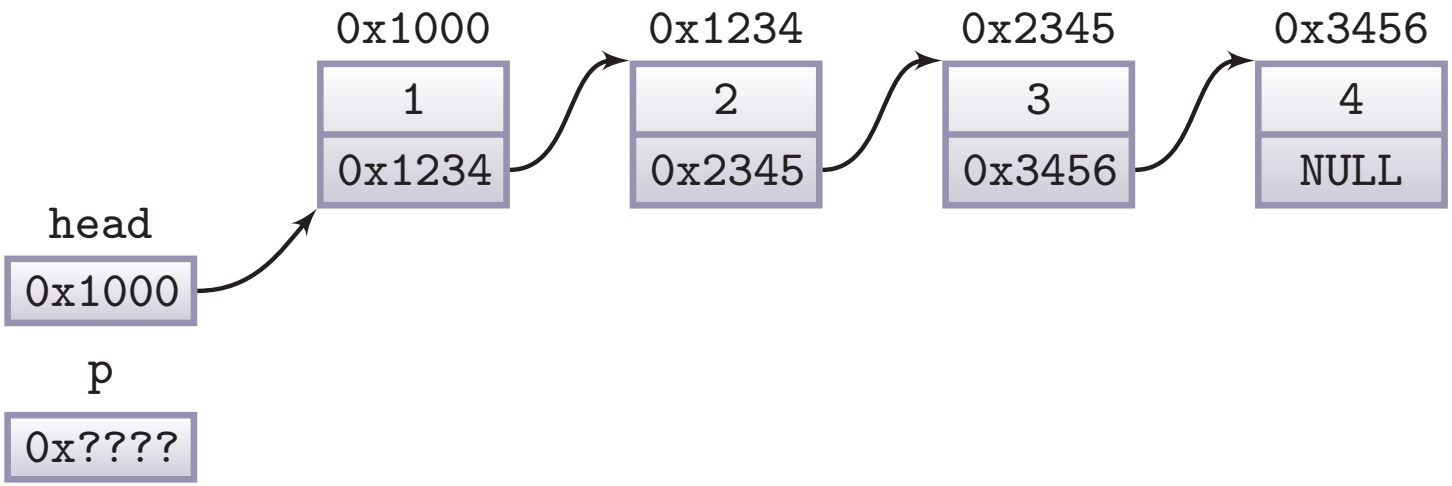

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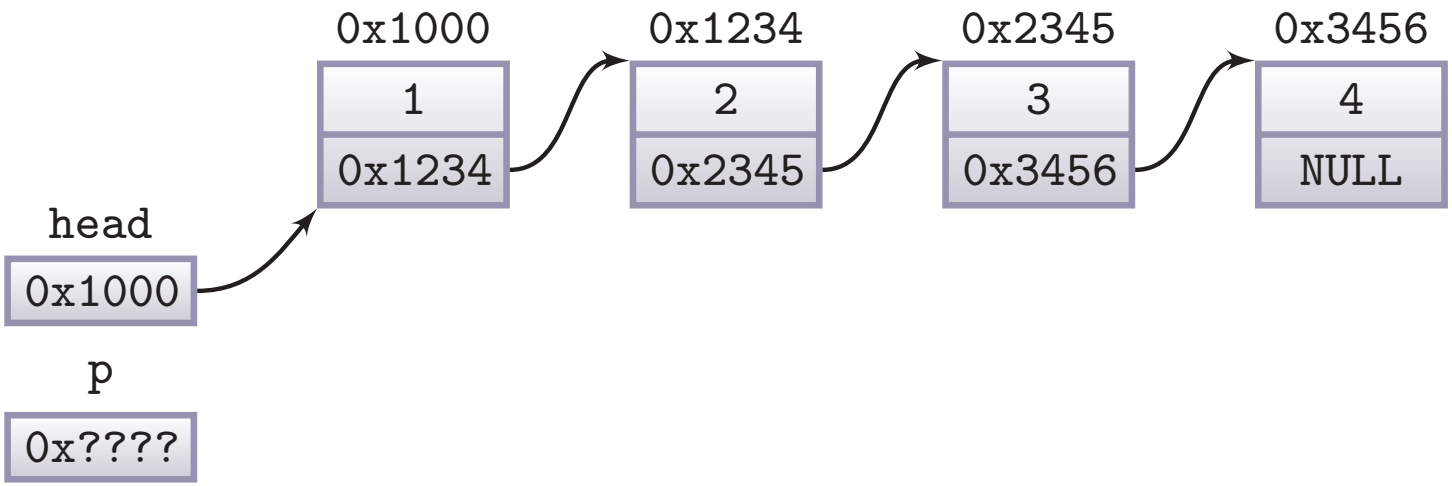

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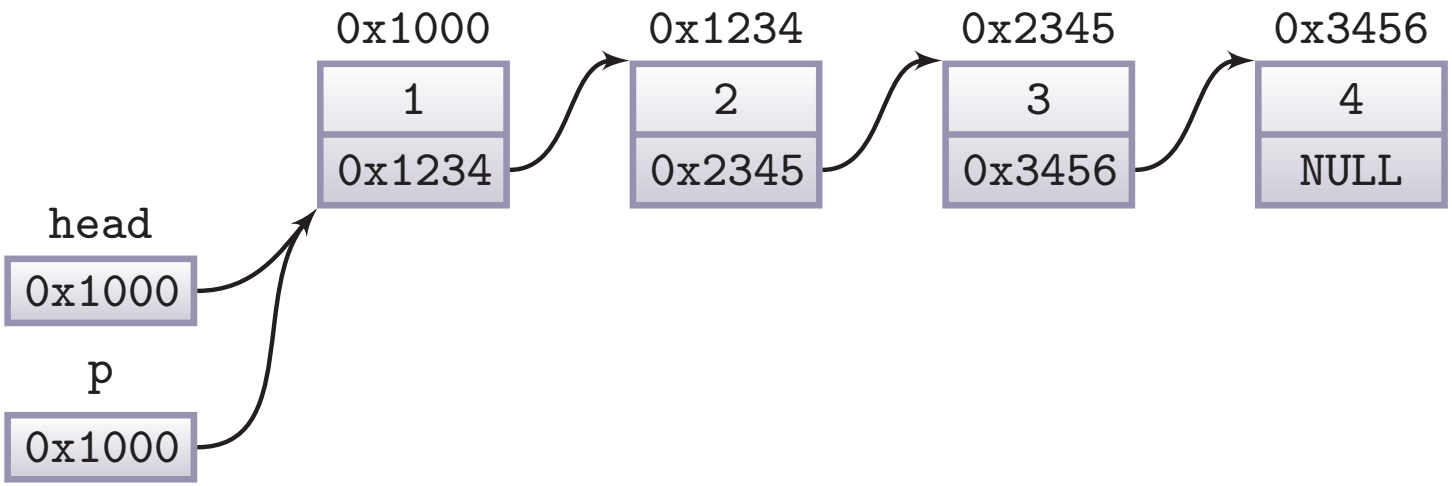

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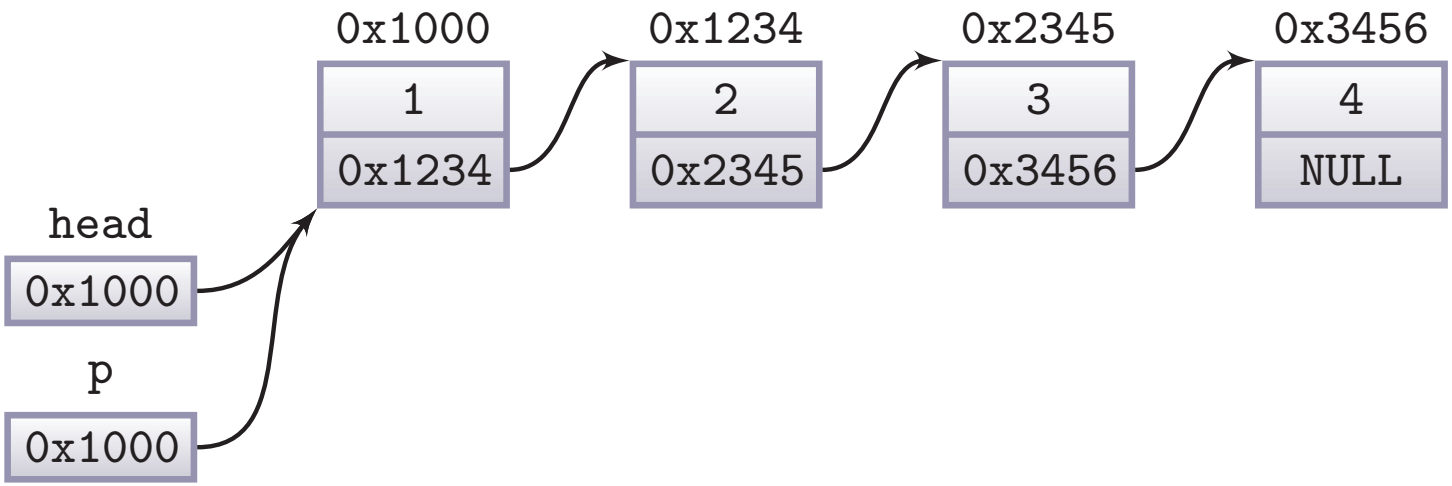

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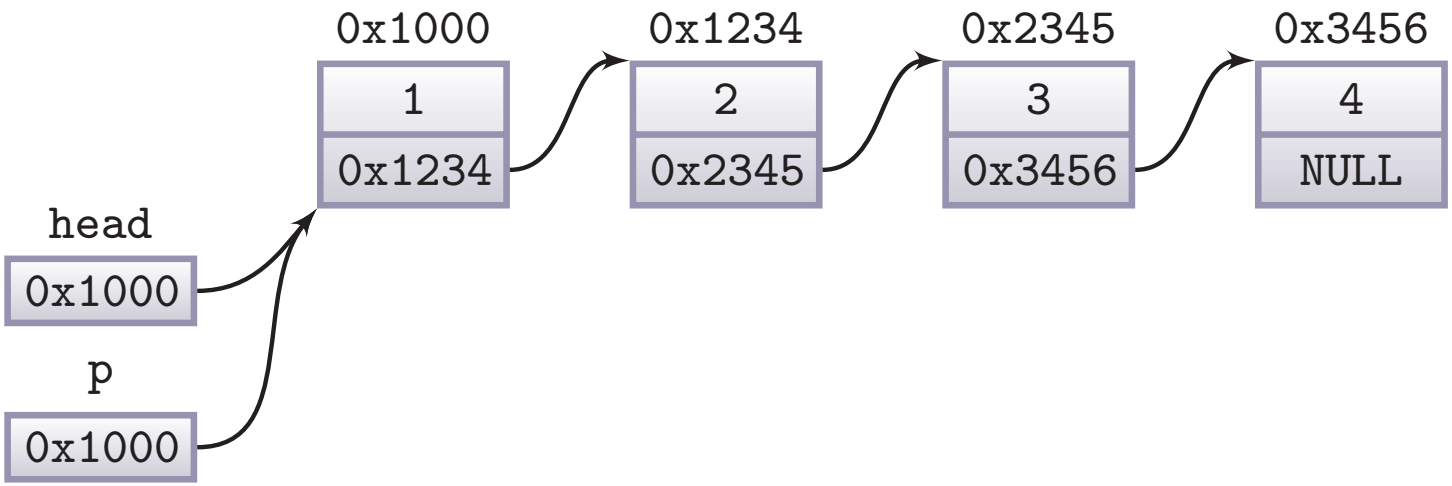

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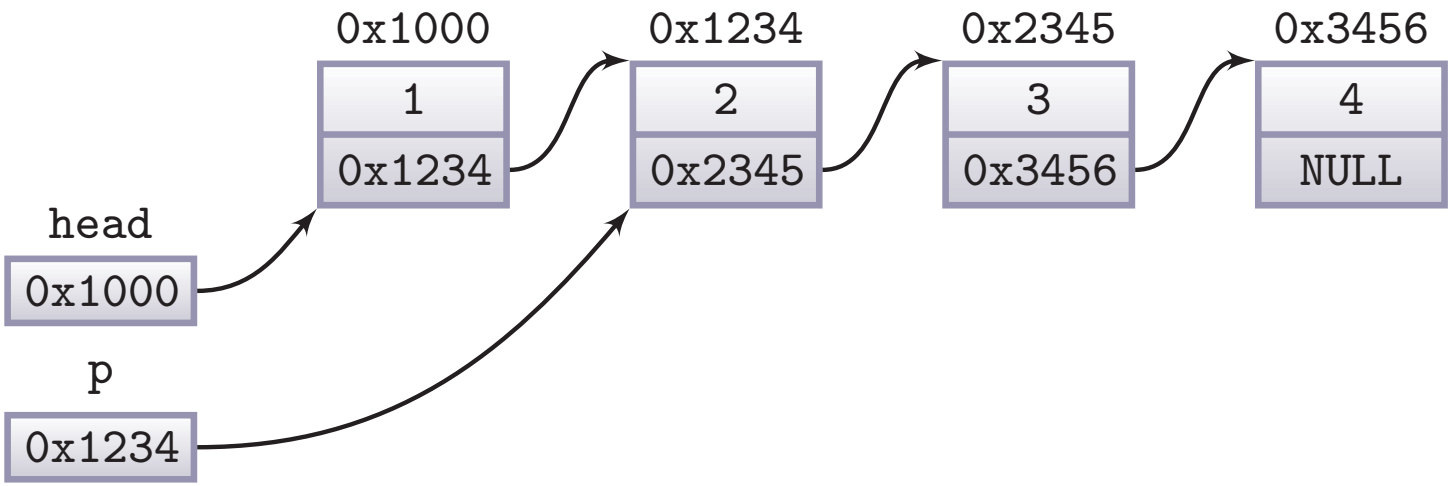

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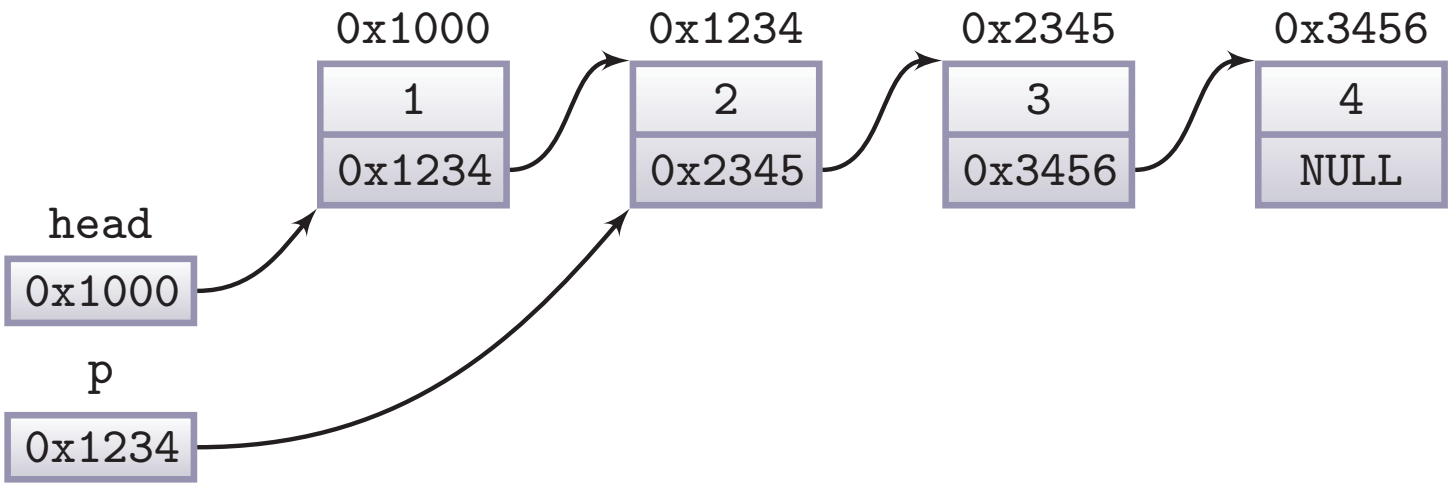

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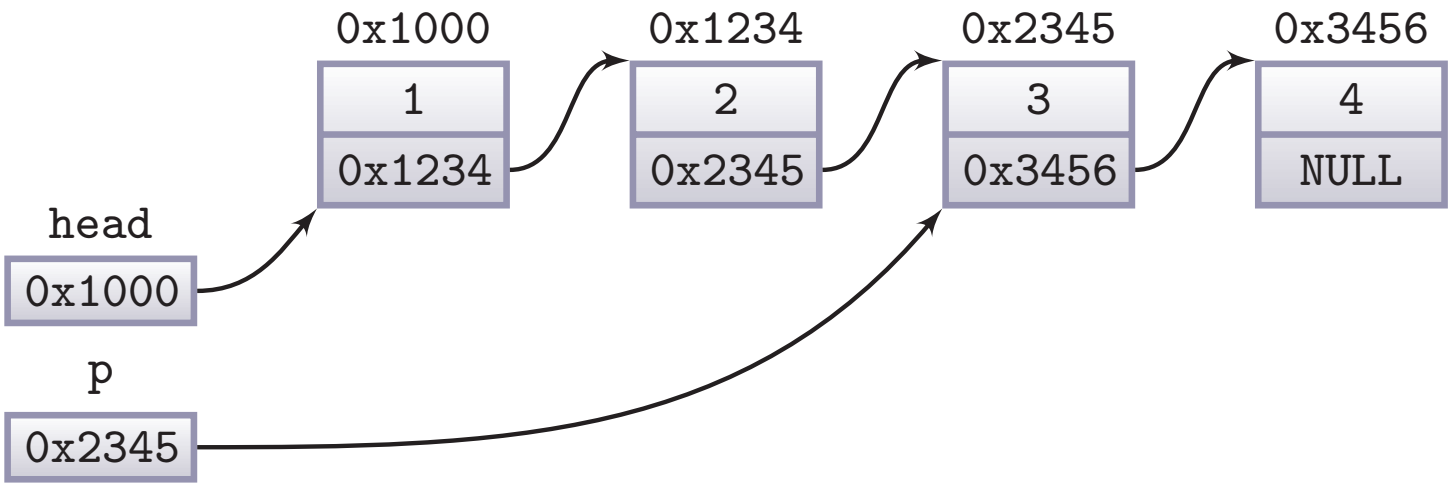

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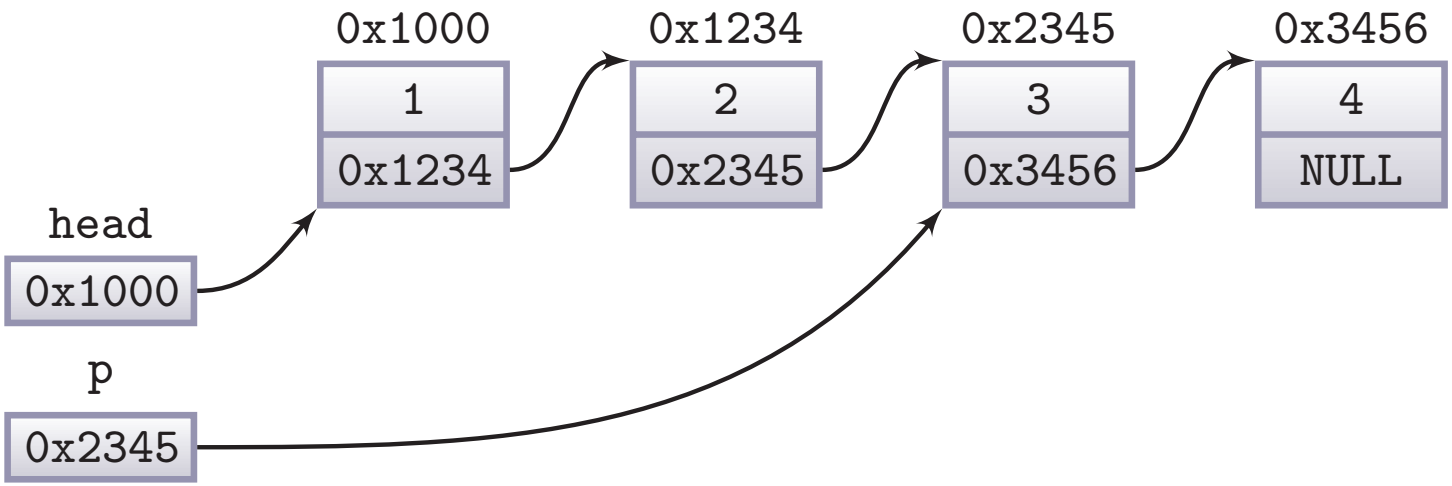

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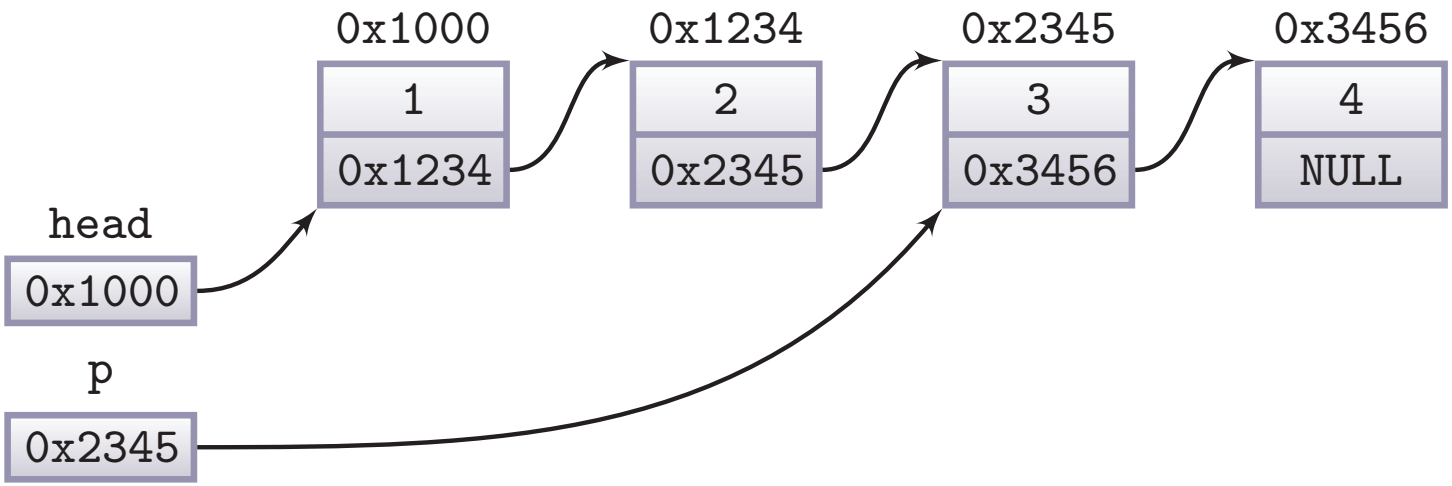

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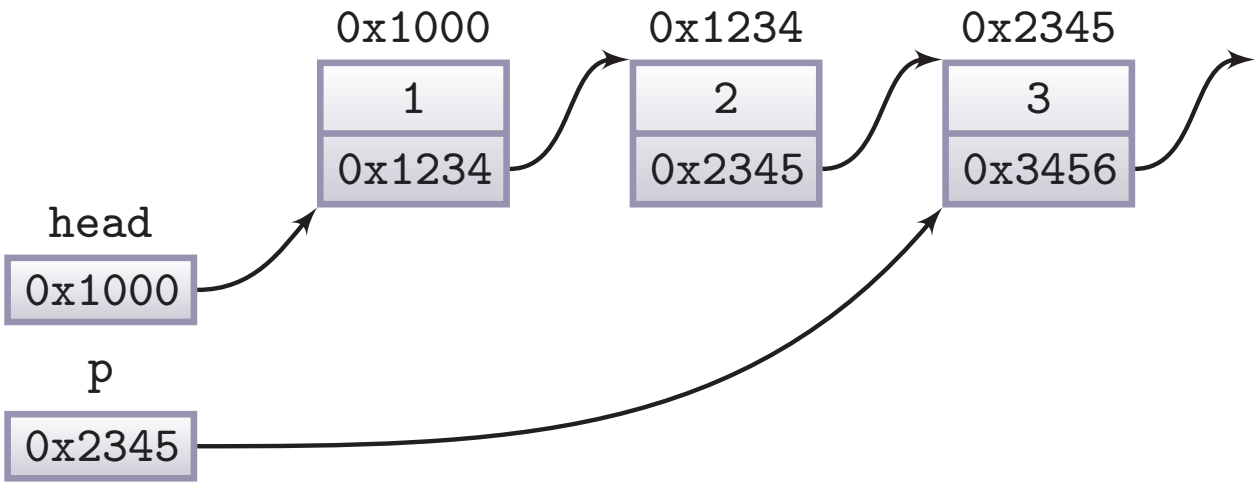

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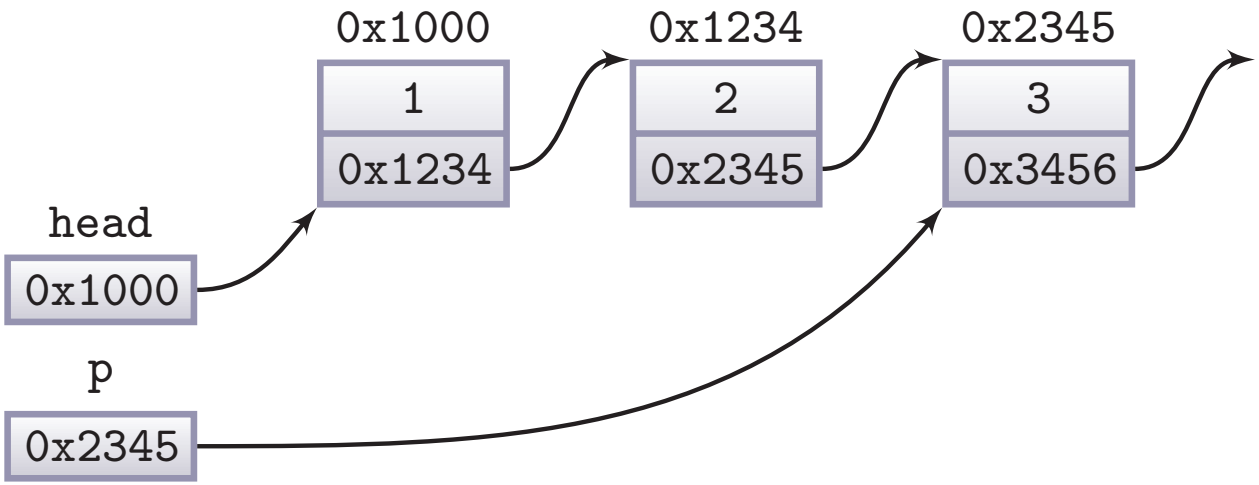

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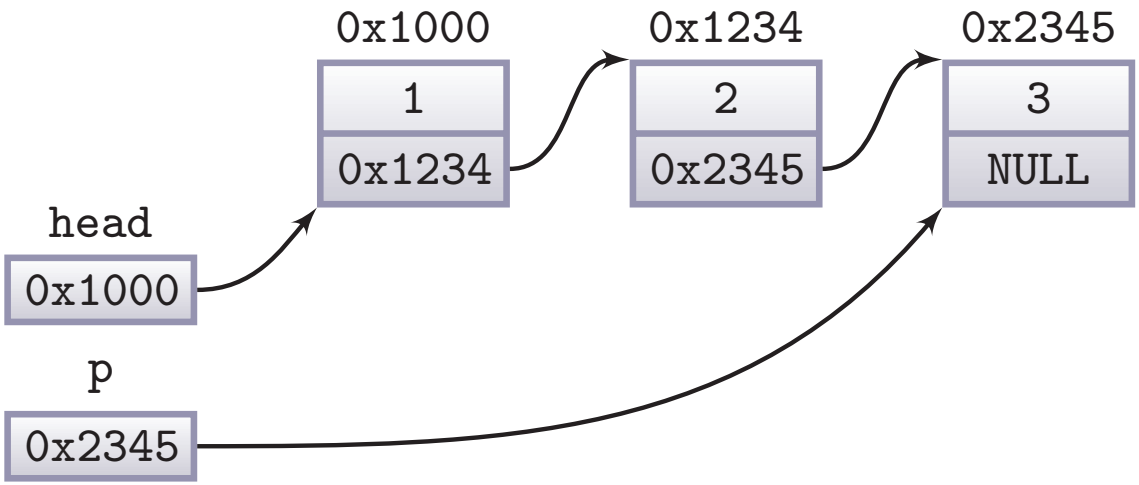

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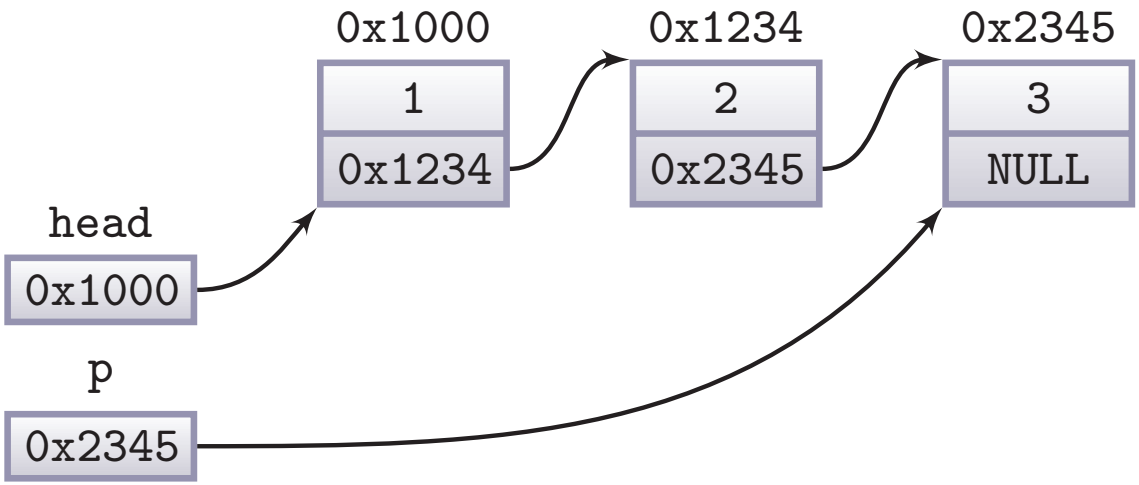

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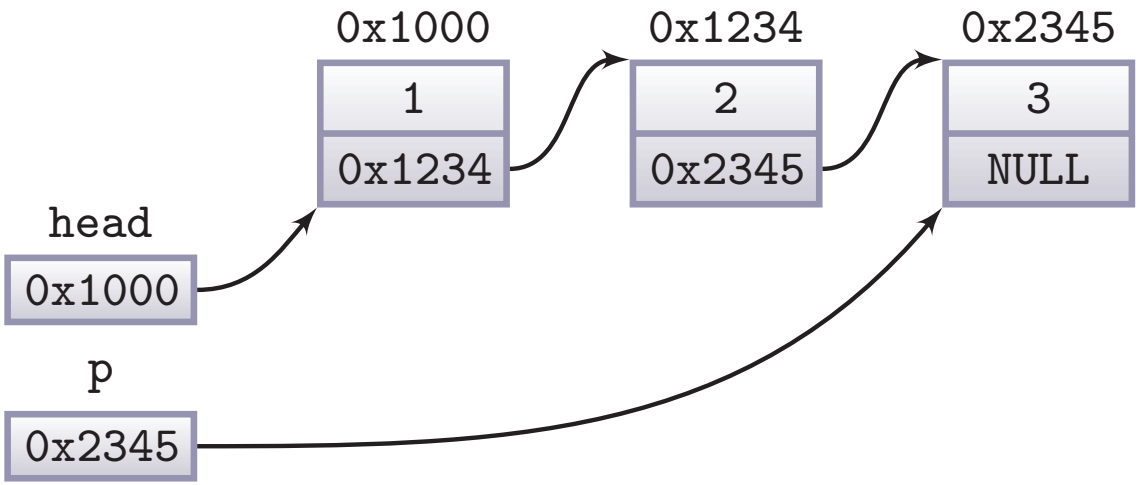

- If the list is empty or it contains only one element, the expression `p->next->next` doesn't make any sense.

Deleting element from the end of the list with a function


```
1  listelem *pop_back(listelem *head)
2  {
3    listelem *p;
4
5    if (head == NULL ) /* empty */
6      return head;
7
8    if (head->next == NULL) /* only one element */
9      return pop_front(head);
10
11   for (p = head; p->next->next != NULL; p = p->next);
12   free(p->next);
13   p->next = NULL;
14   return head;
15 }
```

link

Deleting a given element from list

- Deleting the `data = 3` element

```
1  q = head; p = head->next;
2  while (p != NULL && p->data != data) {
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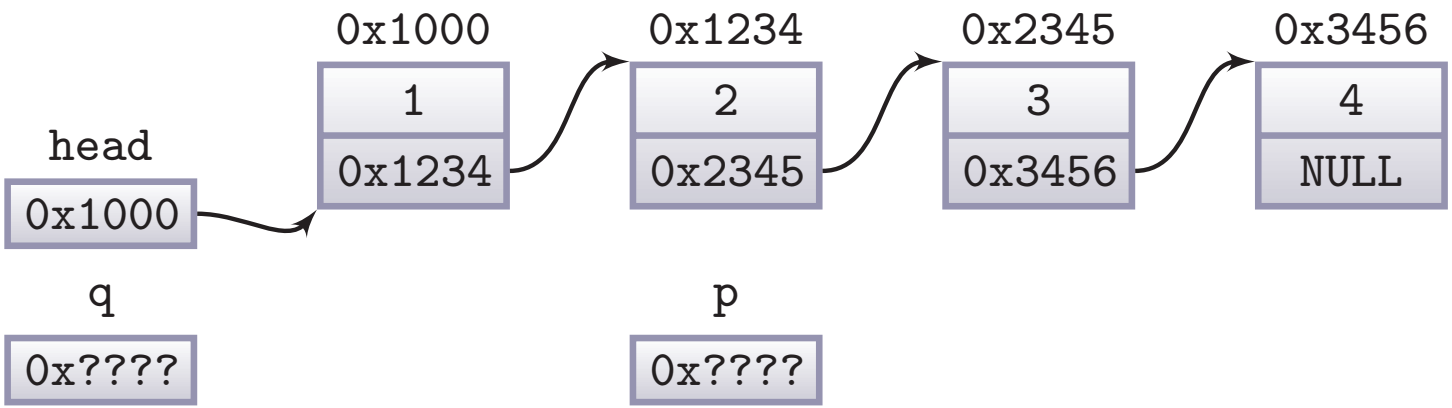

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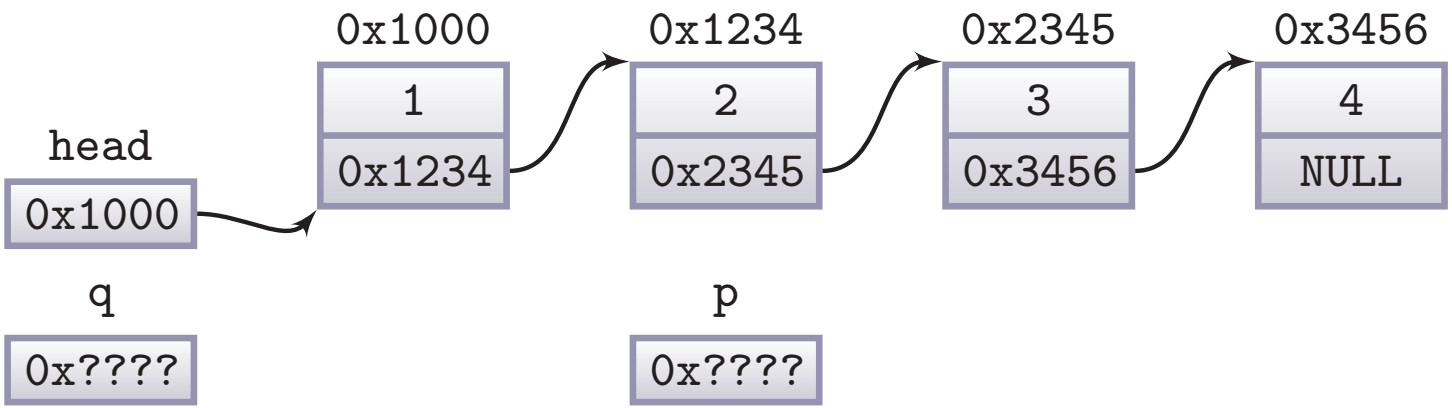

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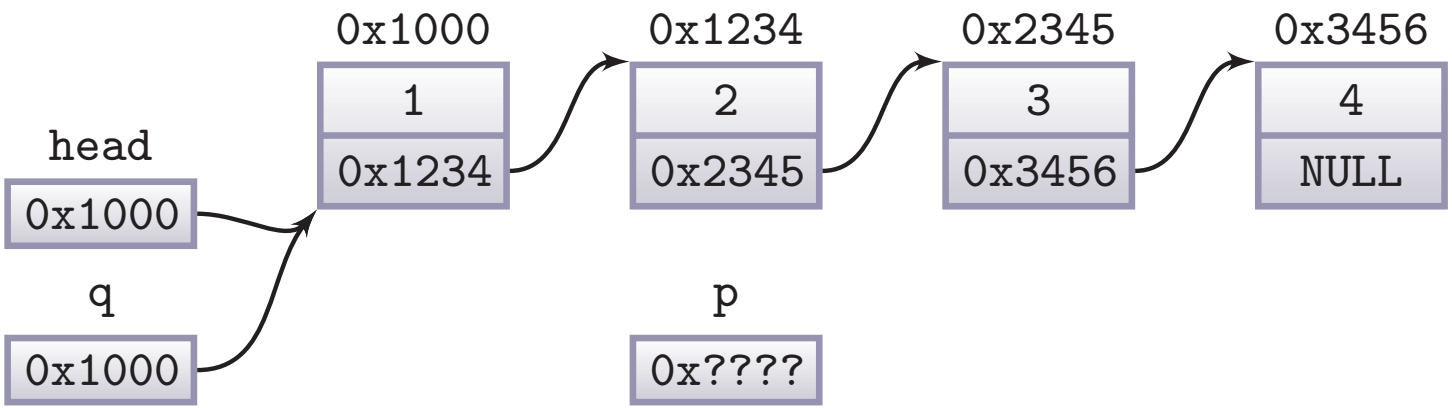

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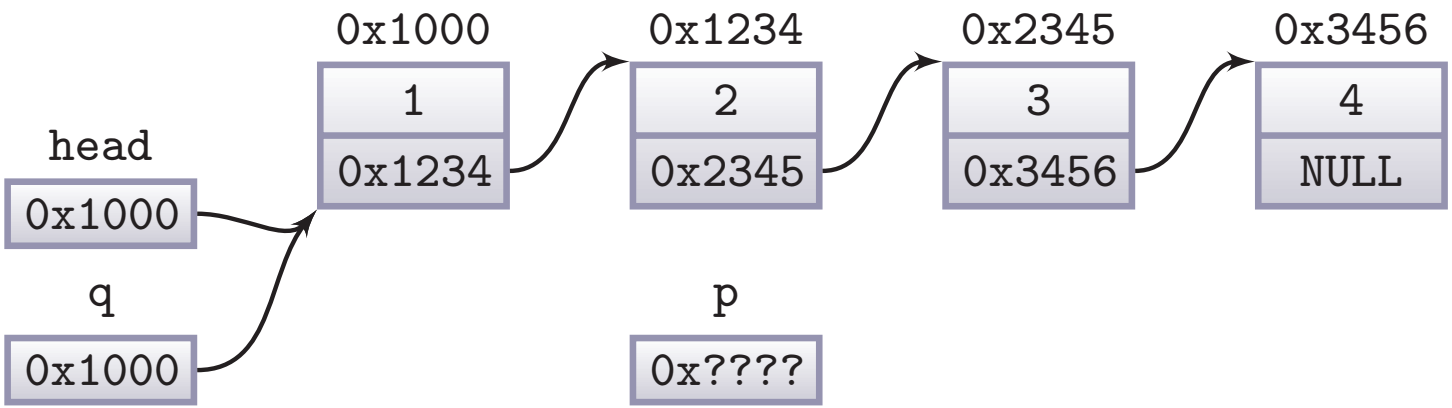

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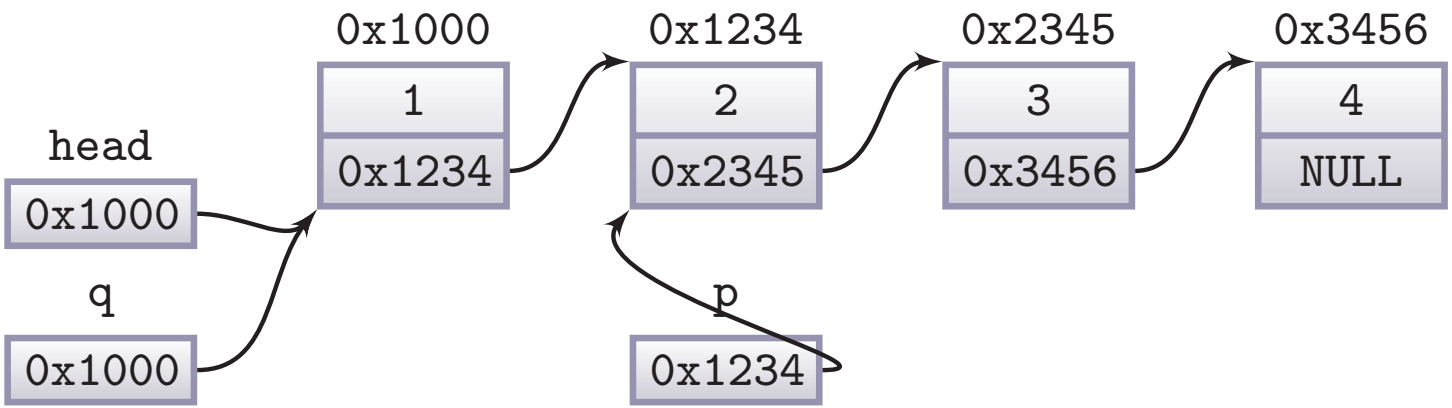

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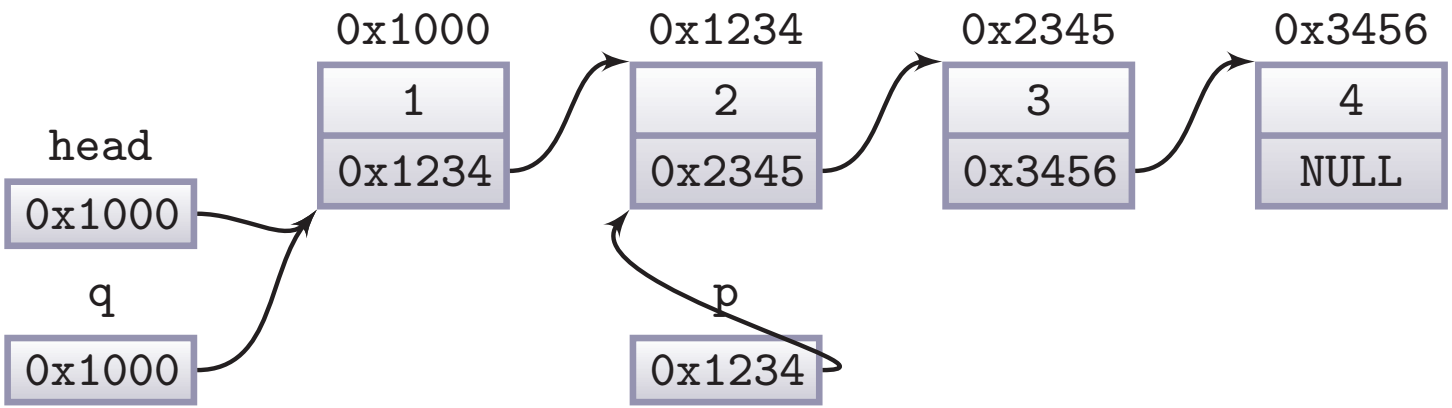

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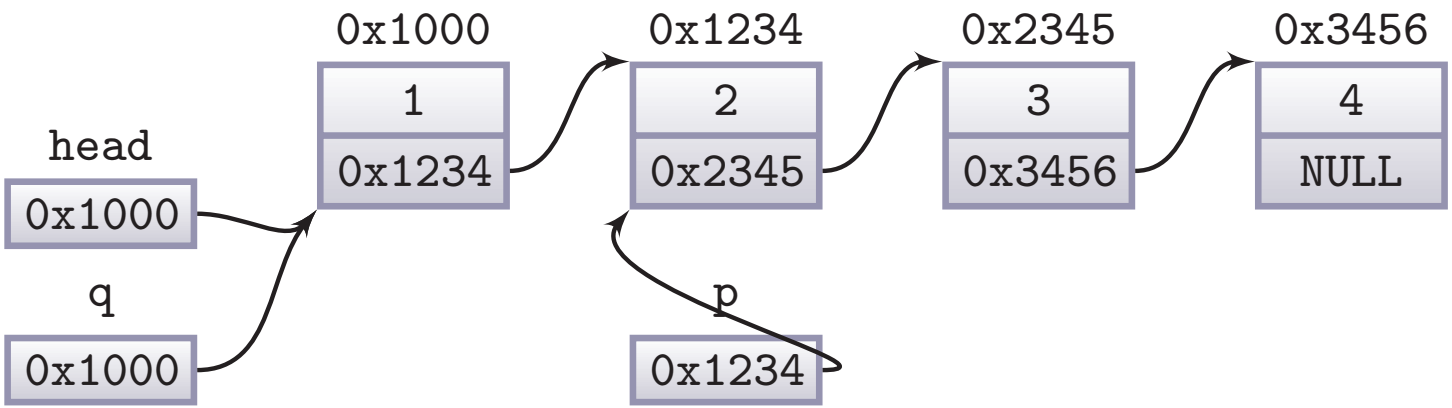

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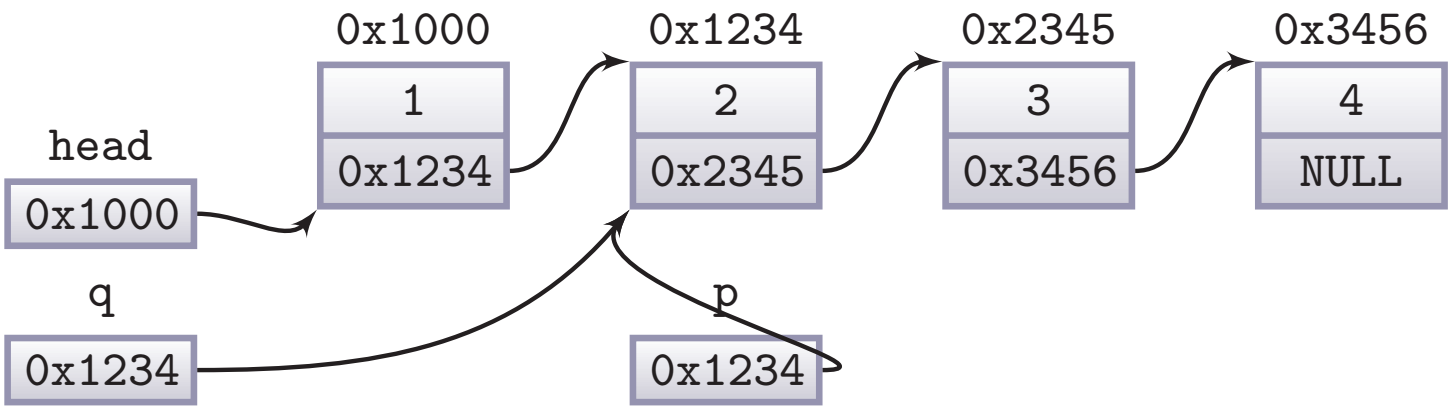

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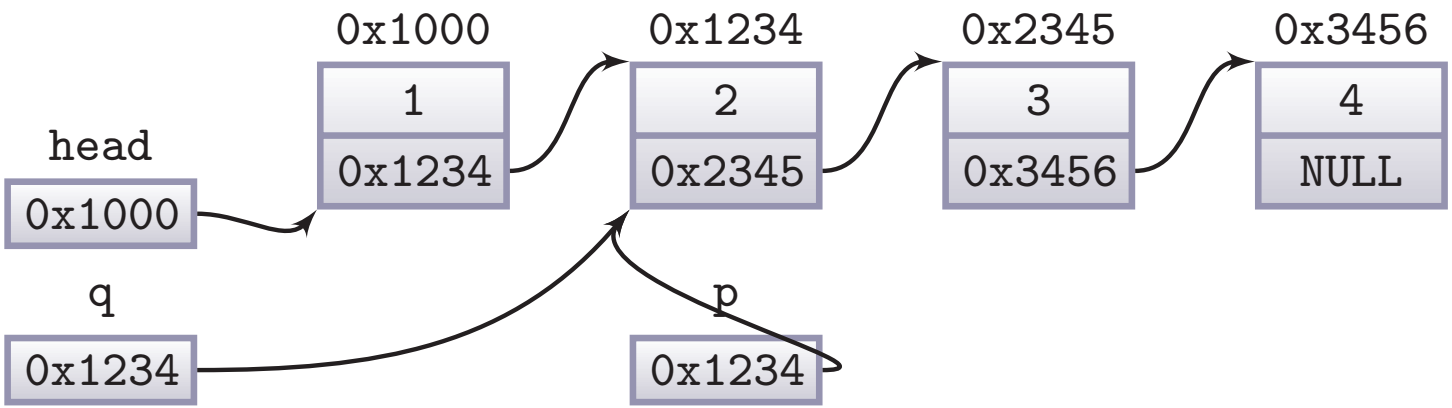

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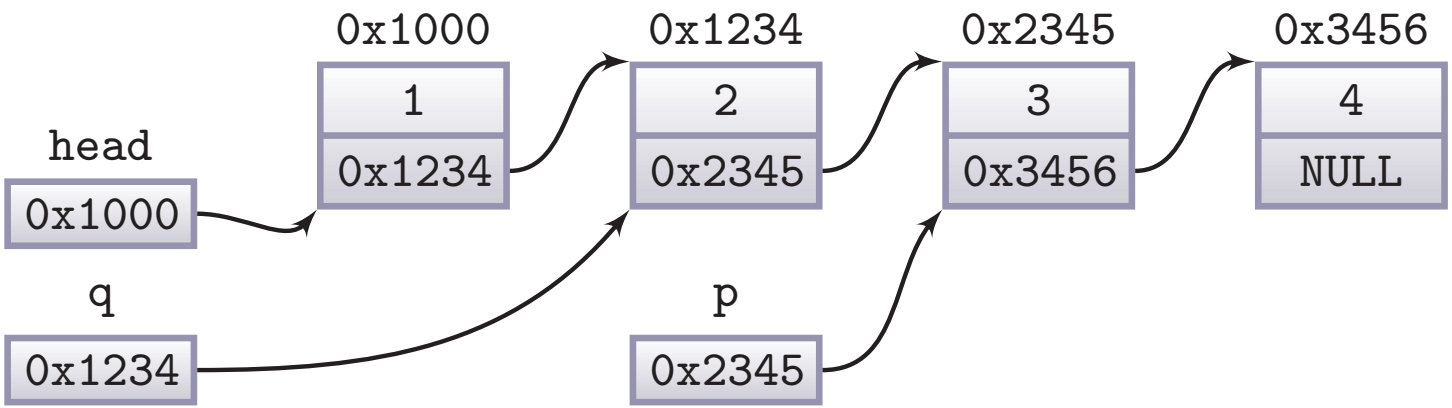

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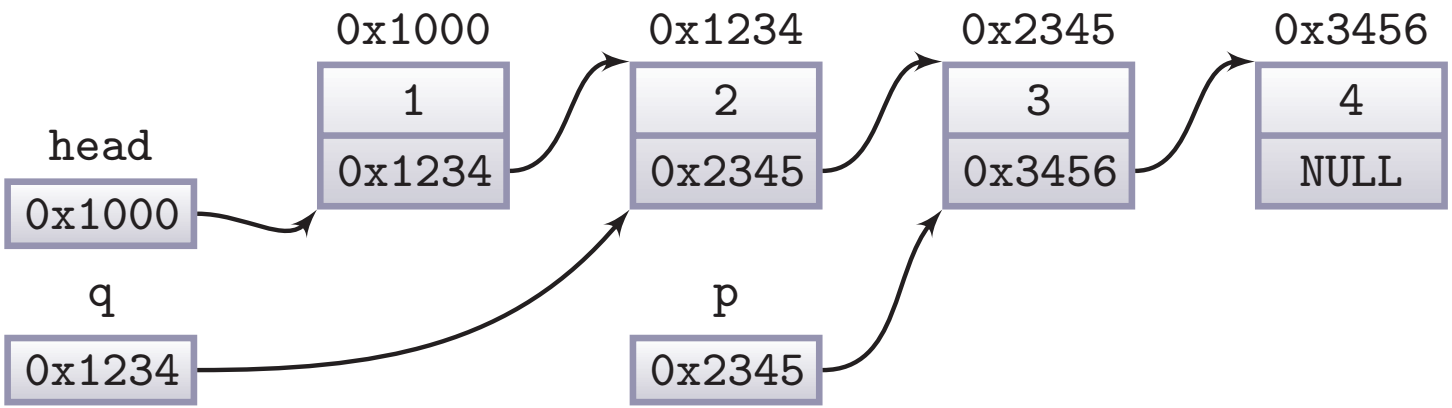

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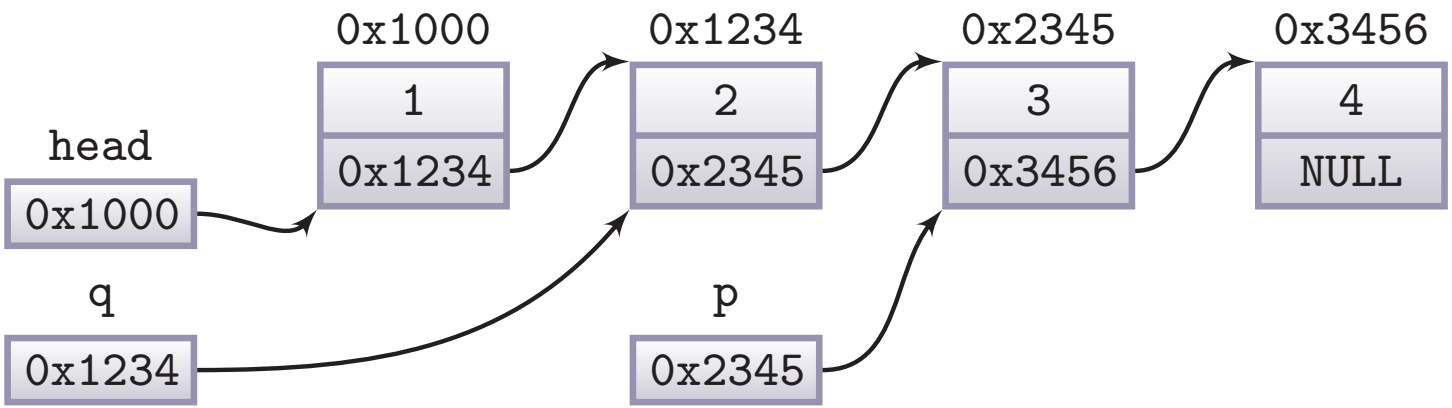

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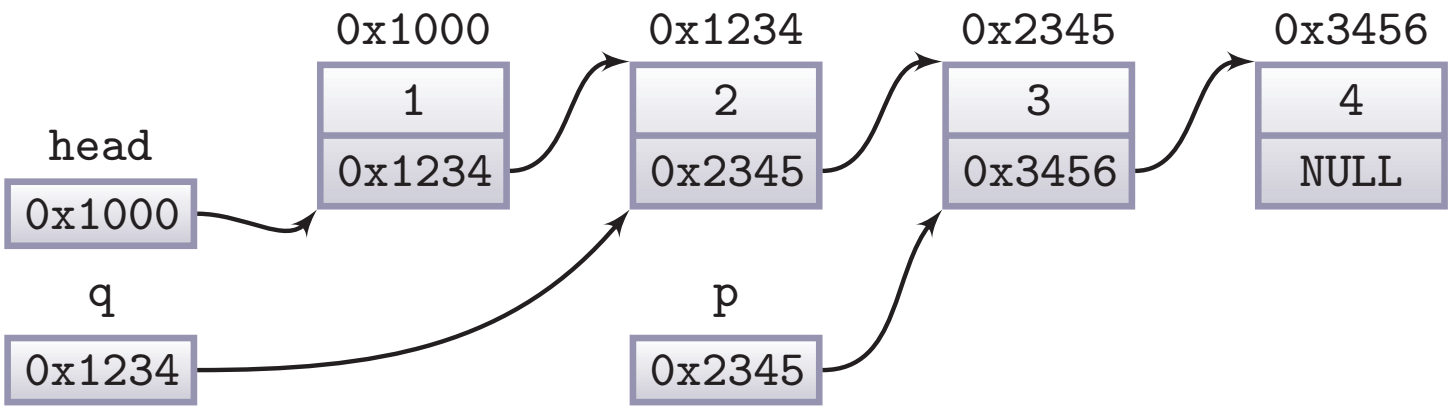

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

- Deleting the `data = 3` element

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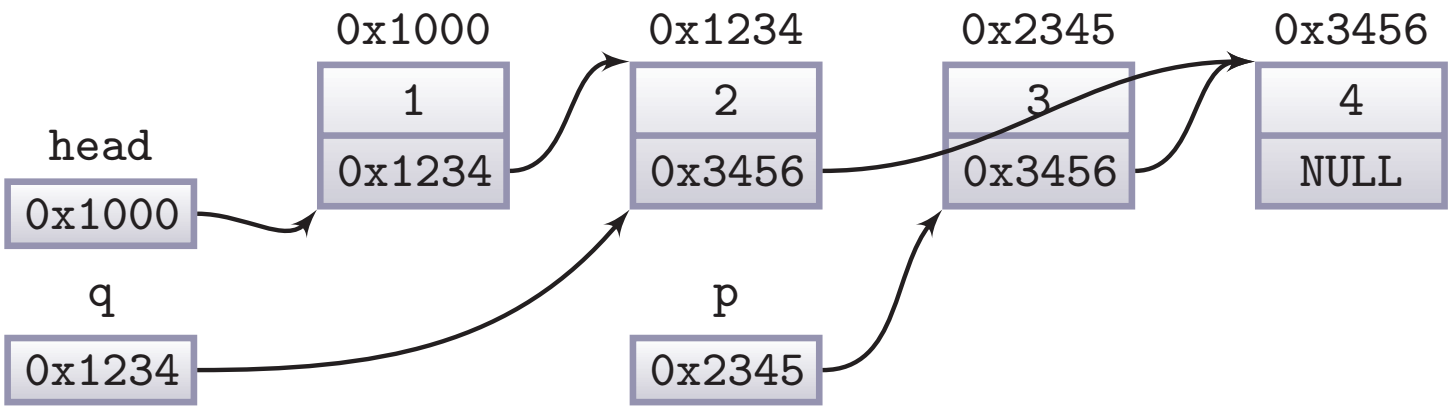

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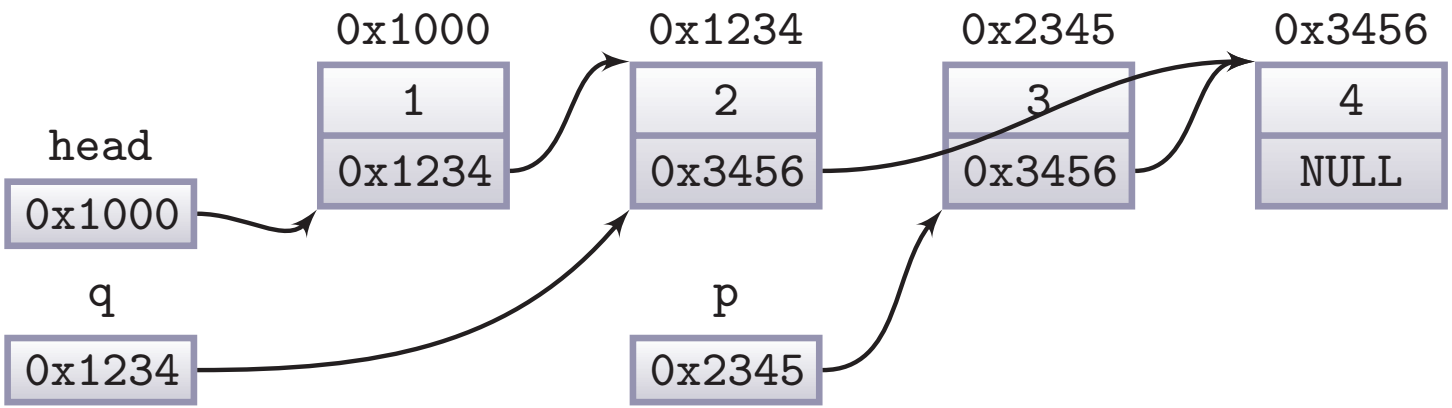

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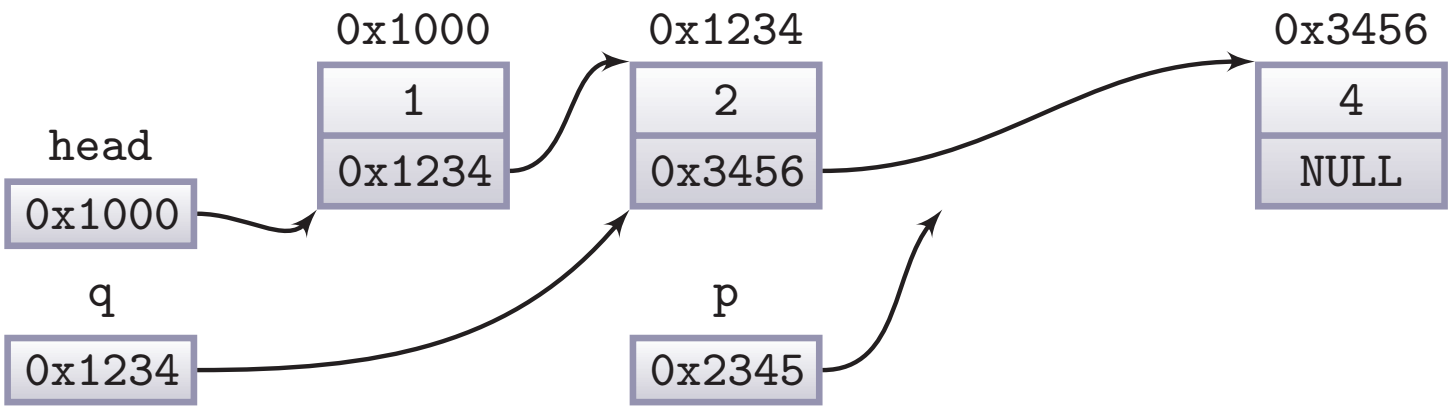

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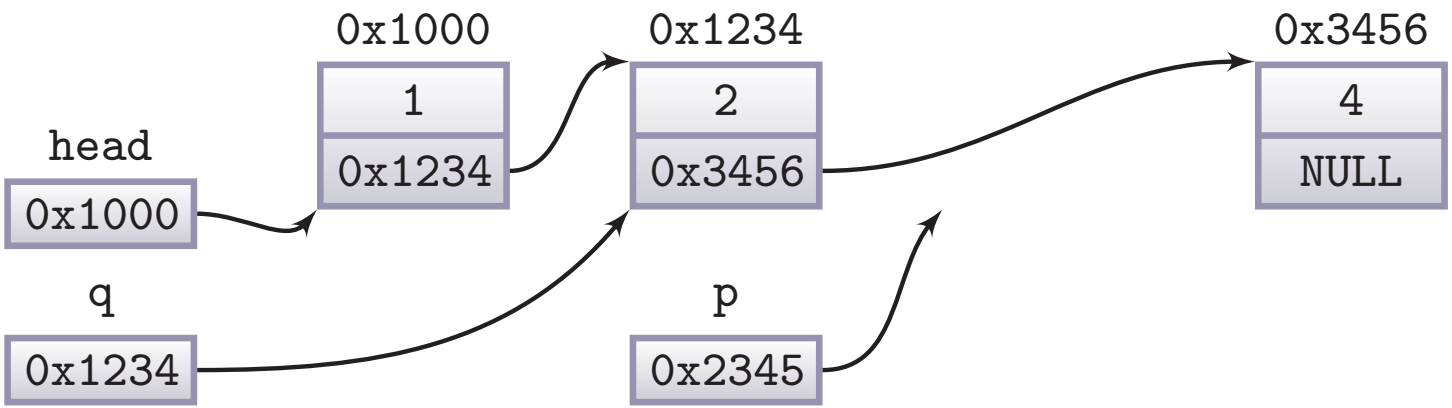

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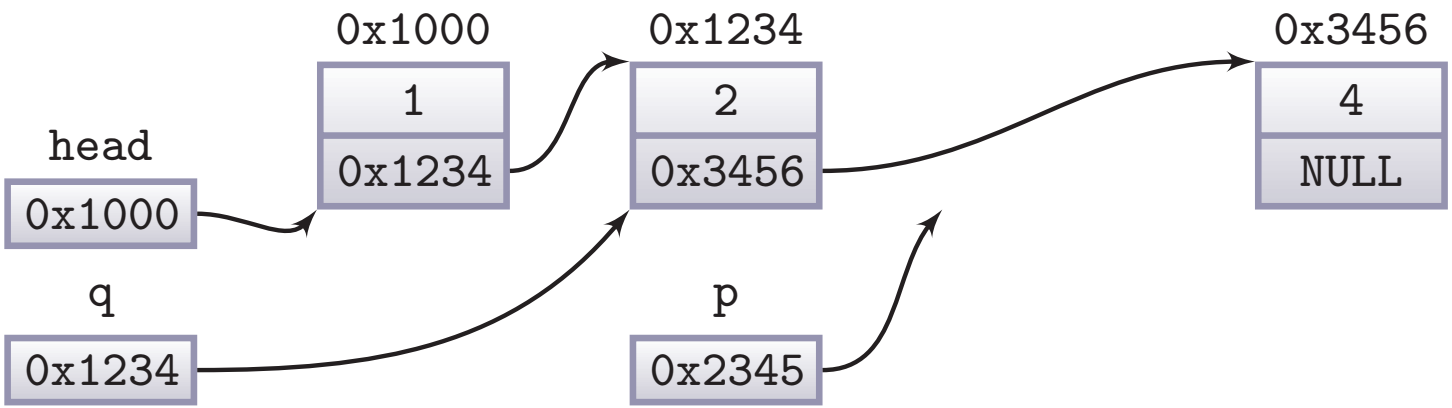

- If the list is empty, or we have to delete the first element, this does not work

Deleting a given element from list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  listelem *delete_elem(listelem *head, int d)
2  {
3    listelem *p = head;
4
5    if (head == NULL) return head;
6
7    if (head->data == d) return pop_front(head);
8
9    while (p->next != NULL && p->next->data != d)
10     p = p->next;
11   if (p->next != NULL)
12   {
13     listelem *q = p->next;
14     p->next = q->next;
15     free(q);
16   }
17   return head;
18 }
```

link

Deleting an entire list

DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

```
1  void dispose_list(listelem *head)
2  {
3    while (head != NULL)
4      head = pop_front(head);
5  }
```

link

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DEPARTMENT OF NETWORKED SYSTEMS AND SERVICES

- We have everything we need, but it was really cumbersome, because
  - we can insert element only after (behind) an element
  - we can delete only an element behind another element
  - empty lists and lists with only one element must be handled separately when inserting or deleting

Thank you for your attention.