Data Structures and Algorithms

(CS210A)

Lecture 26

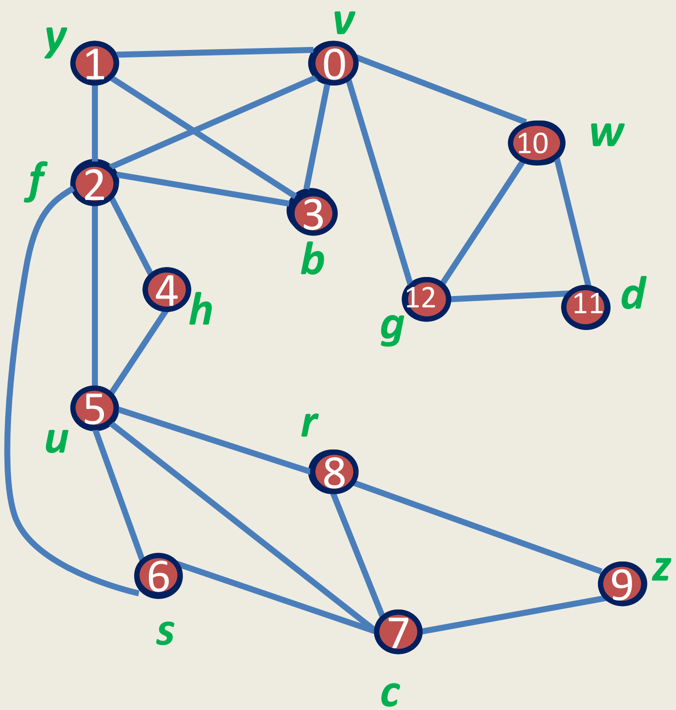
- Depth First Search (DFS) Traversal
- DFS Tree
- Novel application: computing biconnected components of a graph

DFS traversal of *G*

```
DFS(v)
{  Visited(v) ← true;  DFN[v] ← dfn ++;
   For each neighbor w of v
   {        if (Visited(w)  = false)
            {   DFS(w) ;
                 ……..;
            }
            ……..;
   }
}
```

```
DFS-traversal(G)
{  dfn ← 0;
   For each vertex vϵ V  {      Visited(v)← false                  }
   For each vertex v ϵ V {      If (Visited(v ) = false)    DFS(v)   }
}
```

DFN number

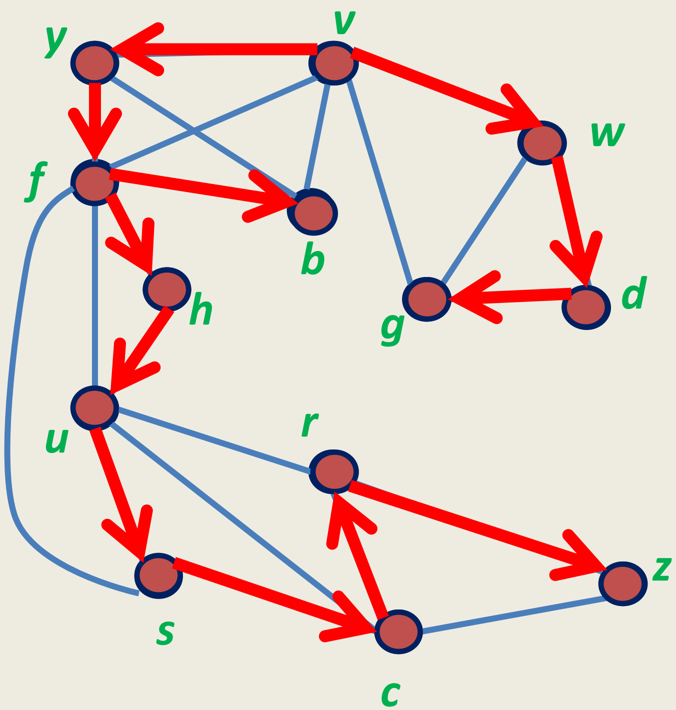


DFN[***x***] :

The number at which ***x*** gets visited during DFS traversal.

DFS tree

DFS(v) computes a tree rooted at v

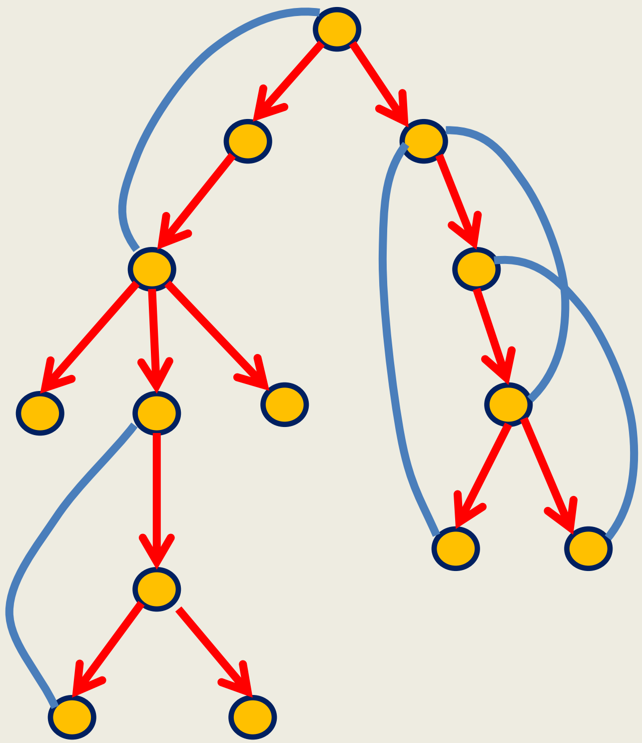


A **DFS** tree rooted at ***v***

Can any rooted tree be obtained through DFS ?

No

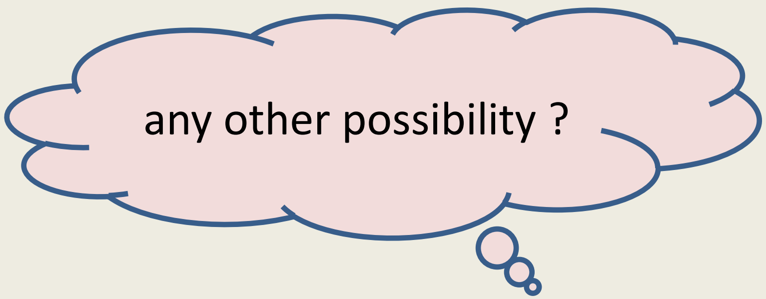
How will an edge appear in DFS traversal ?



- as a **tree-edge**.

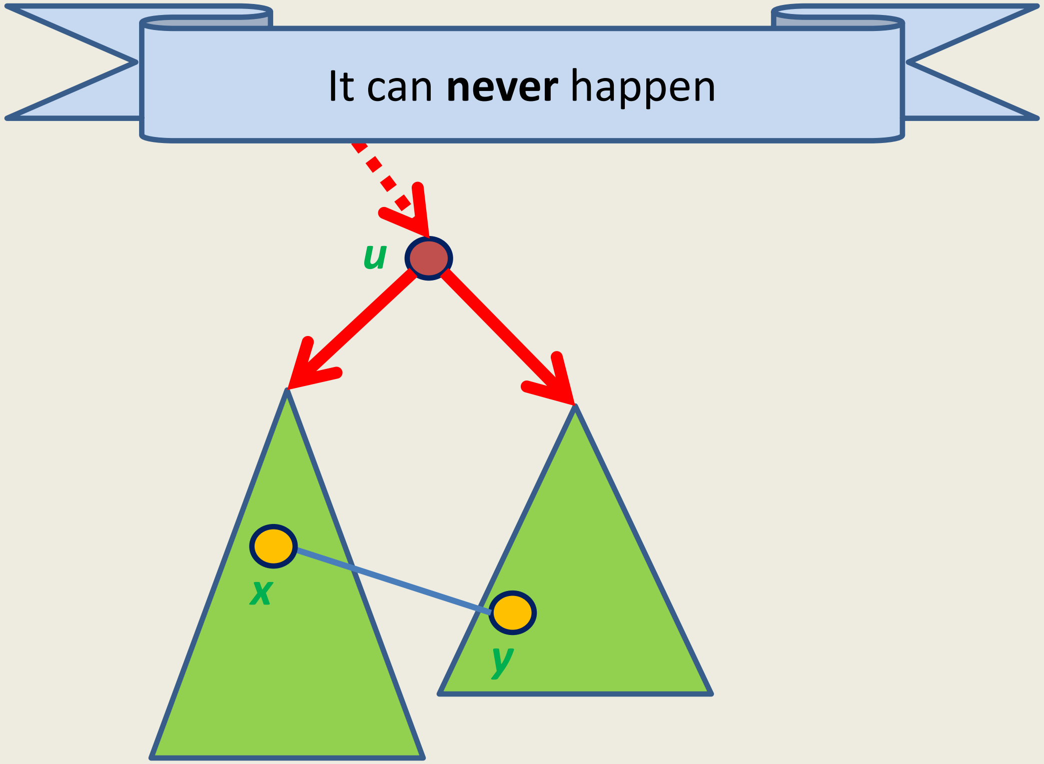
If the edge is a **non-tree** edge :

- Edge between **ancestor** and **descendant** in **DFS** tree.



No

How will an edge appear in DFS traversal ?



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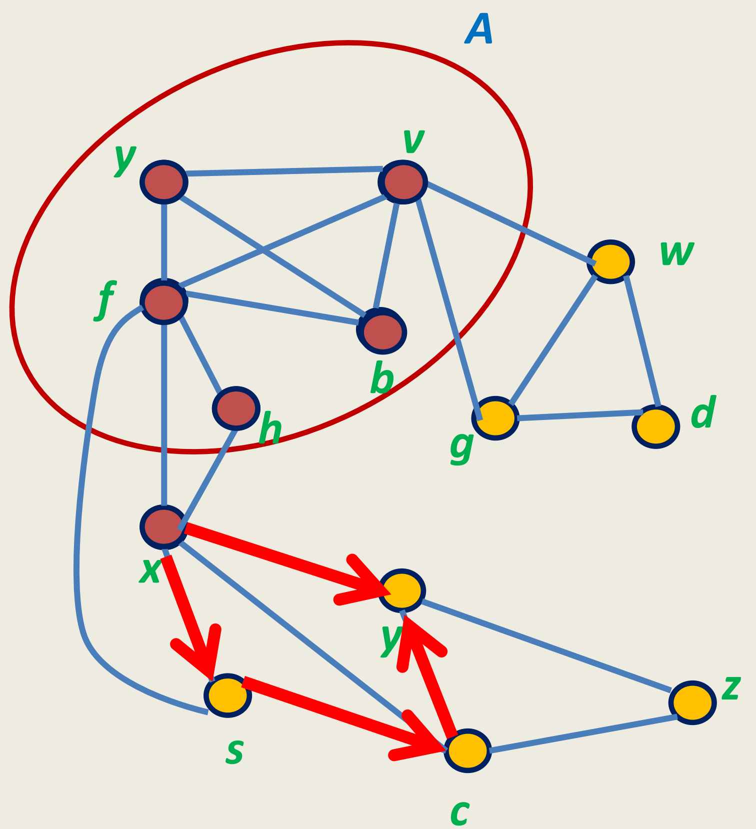


How will an edge appear in DFS traversal ?

A short proof:

Let (***x***,***y***) be a non-tree edge.

Let ***x*** get visited before ***y***.

Question:

If we remove all vertices visited prior to ***x***, does ***y*** still lie in the connected component of ***x*** ?

Answer: yes.

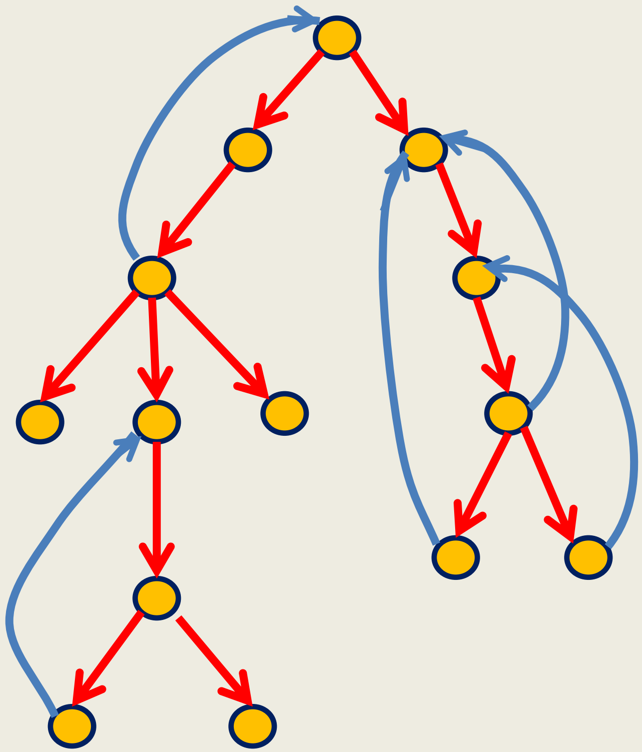
➔

DFS pursued from ***x*** will have a path to ***y*** in **DFS** tree.

Hence ***x*** must be ancestor of ***y*** in the **DFS** tree.

Always remember

the following picture for DFS traversal



non-tree edge ➔ **back** edge

This is called **DFS representation of the graph**.

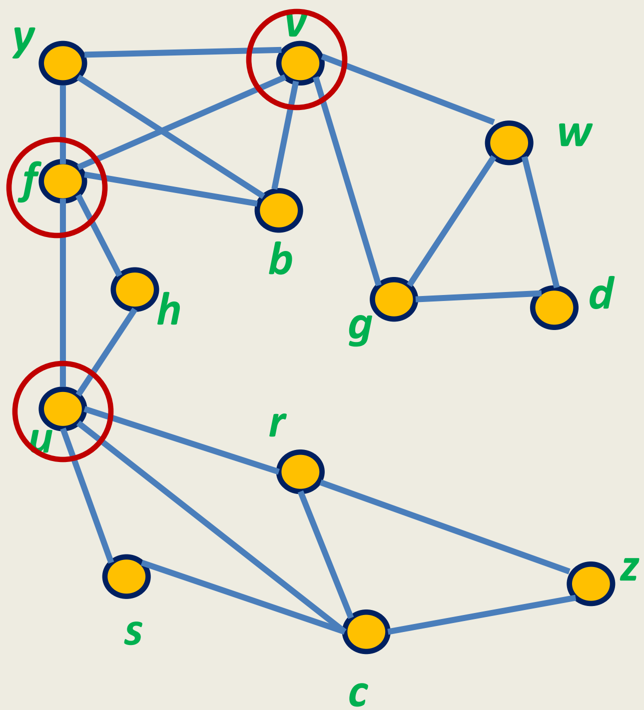
It plays a key role in the design of every efficient algorithm.

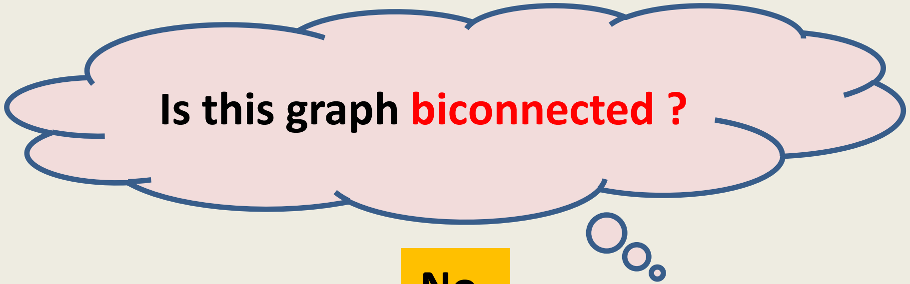
A novel application of DFS traversal

Determining if a graph **G** is **biconnected**

Definition: A connected graph is said to be **biconnected**
if there does not exit any vertex whose removal disconnects the graph.

Motivation: To design **robust** networks
(immune to any single node failure).





No.

A trivial algorithms for checking **bi-connectedness** of a graph

- For each vertex v, determine if $G \setminus \{v\}$ is connected

  (One may use either **BFS** or **DFS** traversal here)

Time complexity of the trivial algorithm : O(mn)

An **O**$(\boldsymbol{m} + \boldsymbol{n})$ time algorithm

A <u>single</u> **DFS** traversal

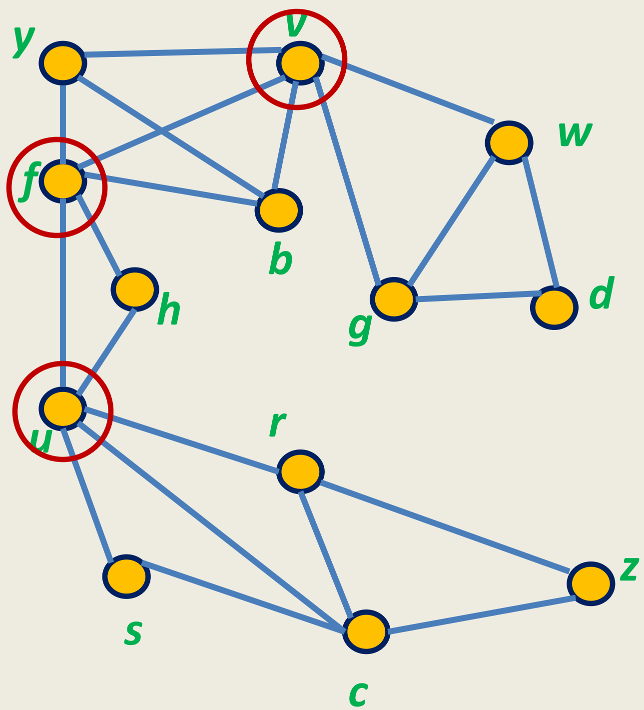
An O($m + n$) time algorithm

- A formal **characterization** of the problem.

  (**articulation points**)

- Exploring **<u>relationship</u>** between articulation point & DFS tree.

- Using the relation **cleverly** to design an efficient algorithm.



This graph is NOT biconnected

The removal of any of {*v*,*f*,*u*} can destroy connectivity.

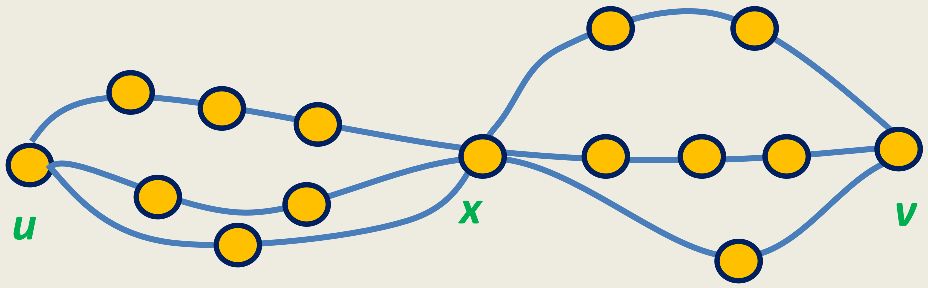
v,*f*,*u* are called the **articulation points** of *G*.

A formal definition of articulaton point

Definition: A vertex ***x*** is said to be **articulation point** if

∃ ***u***,***v*** different from ***x***

such that every path between ***u*** and **v** passes through ***x***.



Observation: A graph is biconnected if none of its vertices is an articulation point.

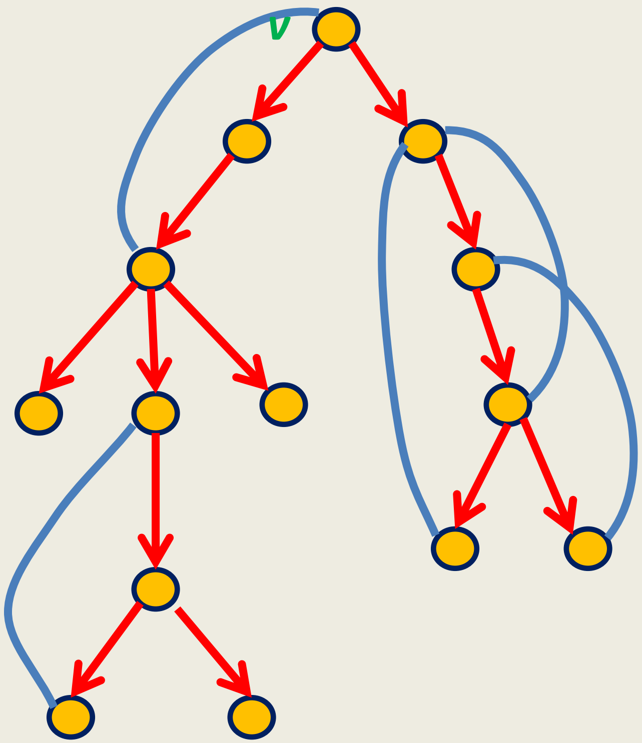
AIM:

Design an **algorithm** to compute all **articulation points** in a given graph.

Articulation points and DFS traversal

Don't Focus on the graph. Instead,
focus on the **DFS tree representation** of the graph.

Some observations

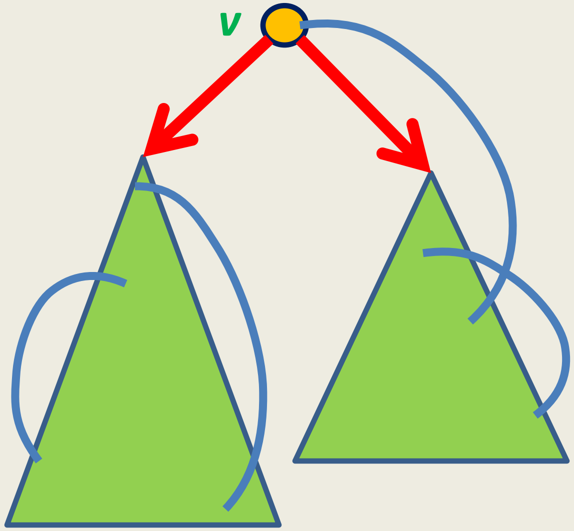


Question: When can **a leaf node** be an **a.p.** ?

Answer: Never

Question: When can **root** be an **a.p**. ?

Some observations



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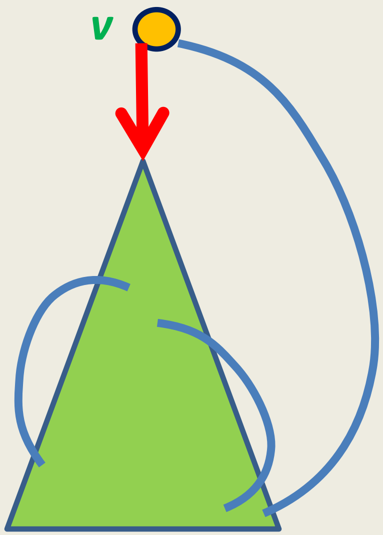


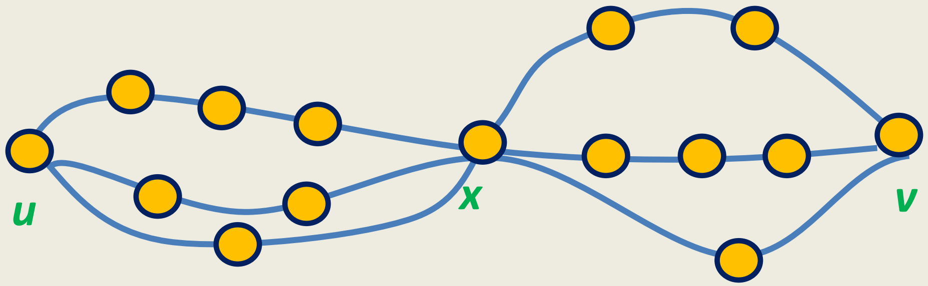
Question: When can **a leaf node** be an **a.p.** ?

Answer: Never

Question: When can **root** be an **a.p**. ?

Answer: Iff it has **two or more** children.

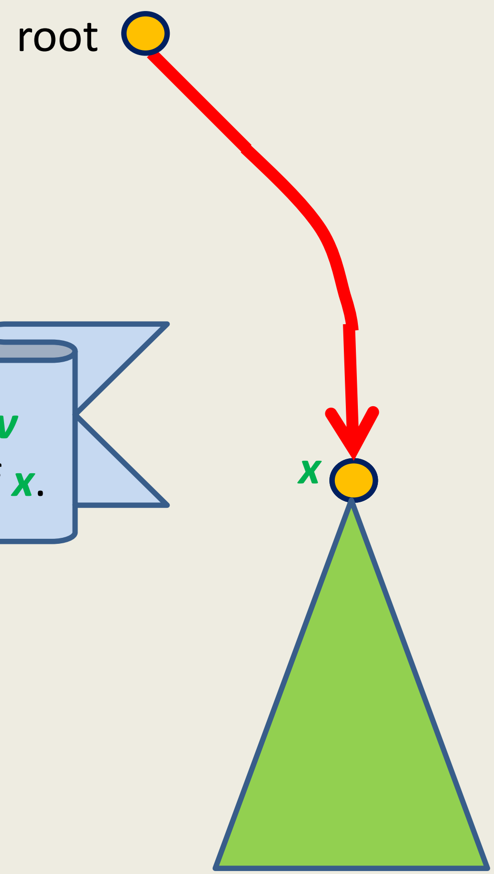
Some observations



AIM:

To find **necessary** and **sufficient conditions** for an **internal node** to be **articulation point**.

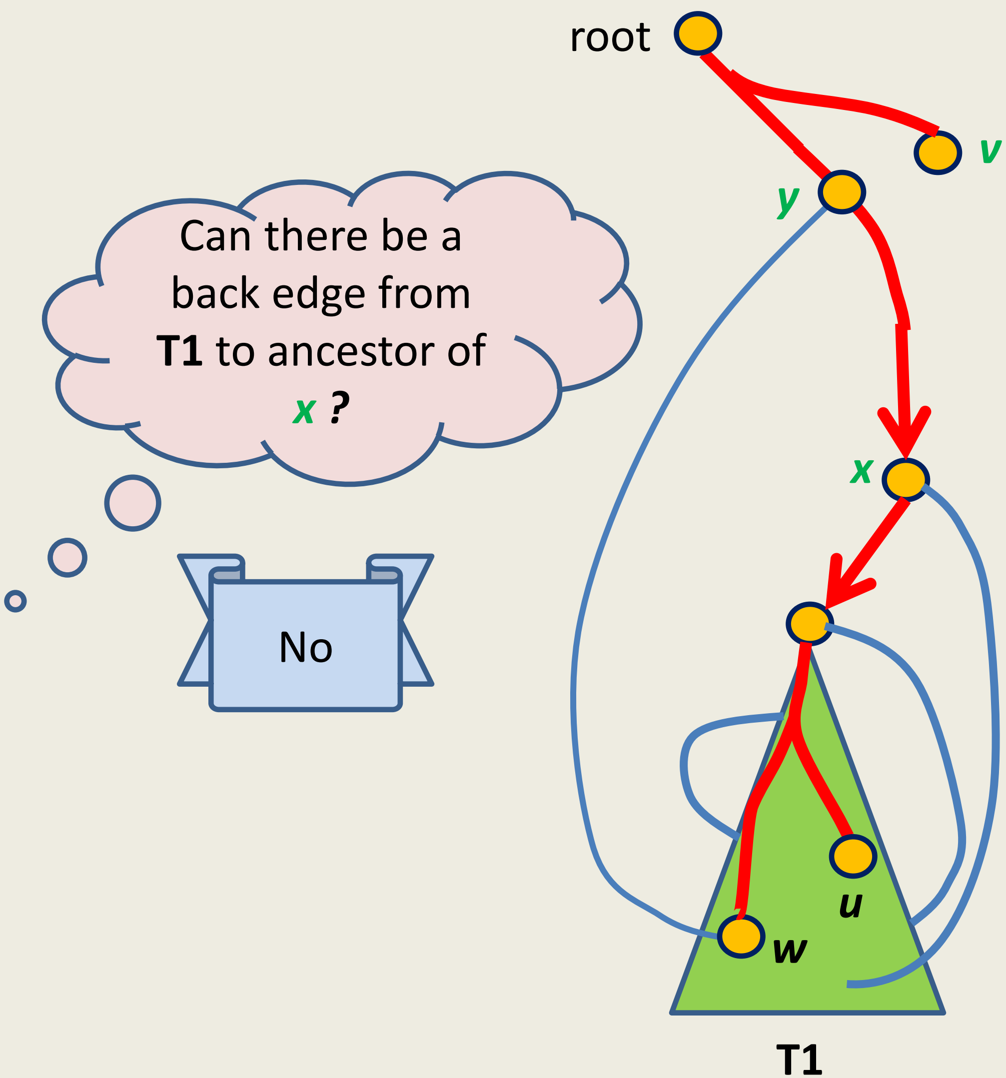
conditions for an **internal node** to be **articulation point**.



At least one of ***u*** and ***v*** must be **descendant** of ***x***.

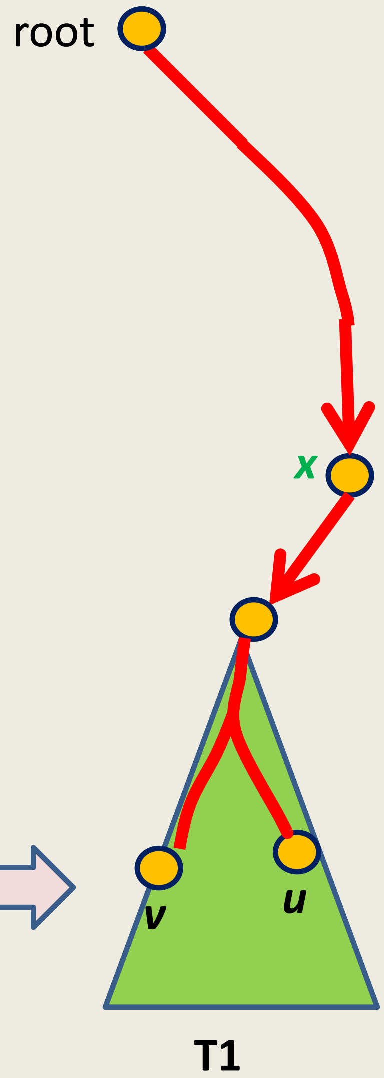
Where will ***u*** and ***v*** be relative to ***x*** ?

Case 1: Exactly one of u and v is a descendant of x in DFS tree



u—*w*—*y*—*v* :
a *u*-*v* path not passing through *x*

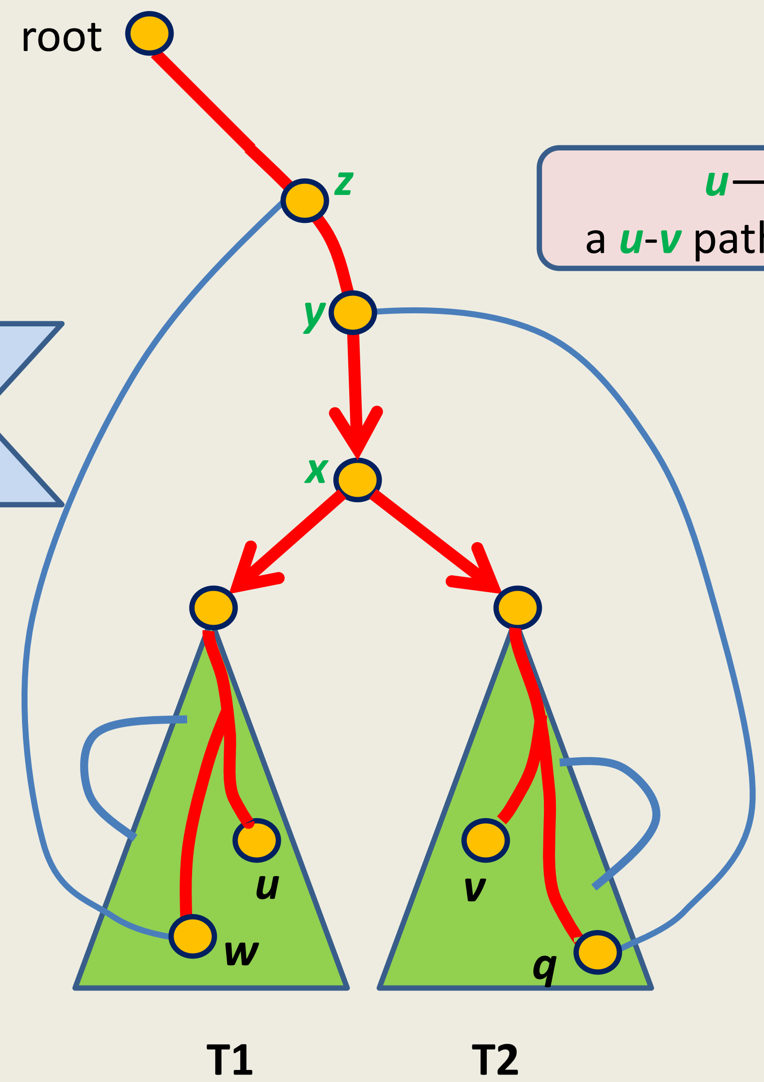
Case 2: both u and v are descendants of x in DFS tree



Can ***u*** and ***v*** belong to **T1** simultaneously?

No

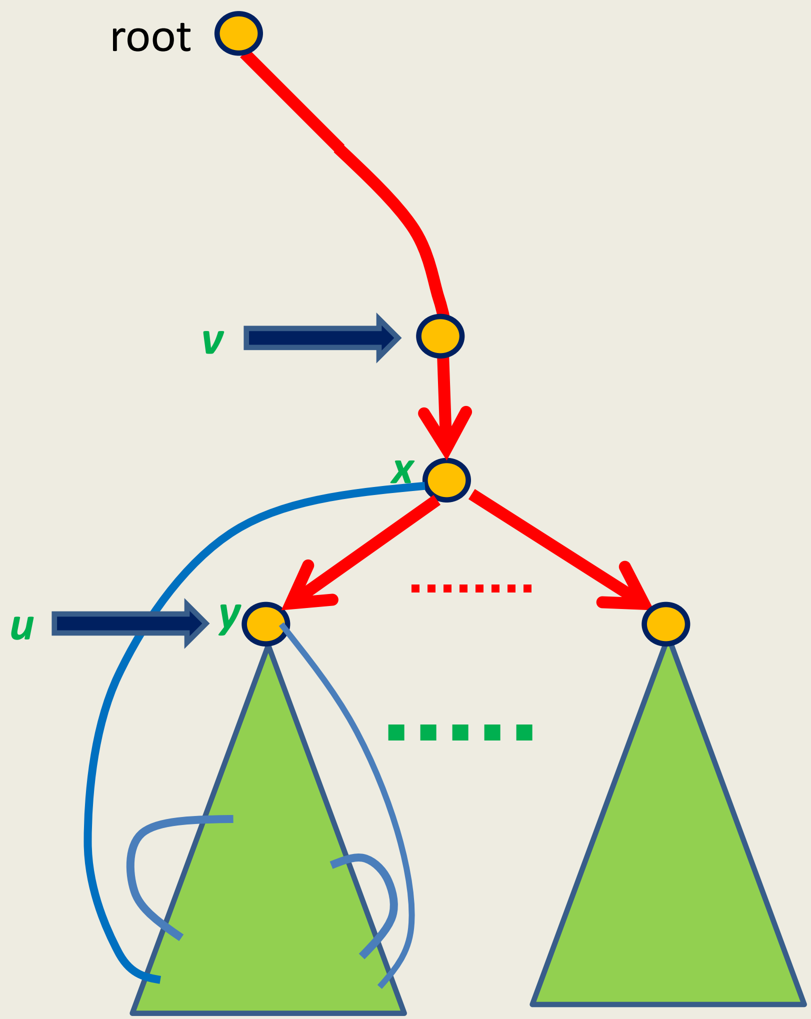
Case 2: both u and v are descendants of x in DFS tree



u—*w*—*z*—*y*—*q*—*v* :
a *u*-*v* path not passing through *x*

At least one of **T1** and **T2** have no back edge to ancestor of *x*

Necessary condition for *x* to be articulation point

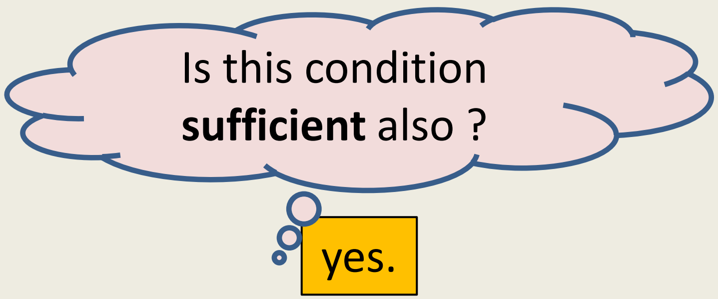


Necessary condition:

x has **at least** one child *y* s.t.

there is **no** back edge

from **subtree**(y) to **ancestor** of *x*.



Articulation points and DFS

Let ***G***=(***V***,***E***) be a connected graph.

Perform **DFS** traversal from any graph and get a DFS tree ***T***.

- No leaf of ***T*** is an **articulation point**.
- root of ***T*** is an **articulation point** if and only if it has more than one child.
- For any internal node … ??

Theorem1 : An internal node ***x*** is **articulation point** **if and only if**

it has a child ***y*** such that

there is **no** back edge

from **subtree**(***y***) to any ancestor of ***x***.

Efficient algorithm for Articulation points

Use Theorem 1

Exploit recursive nature of DFS

Ponder over it before tomorrow's class ☺