

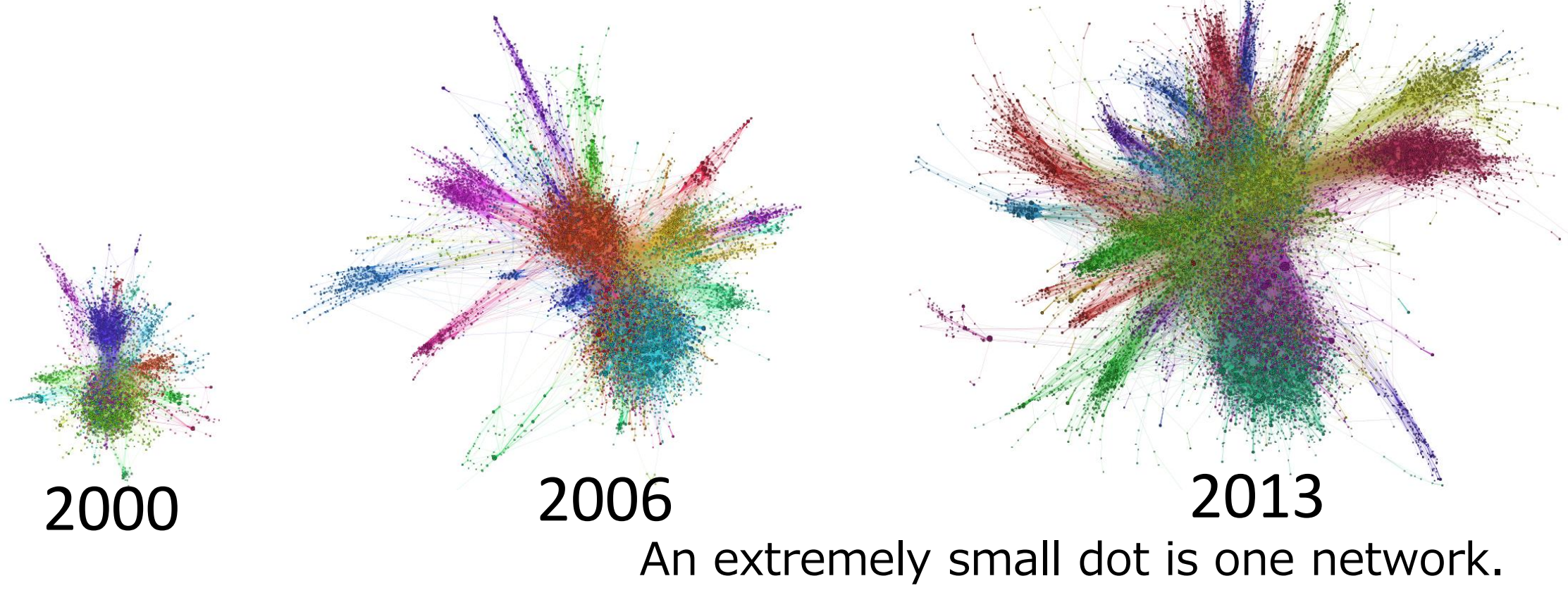
Understanding the evolution of the Internet topology through hierarchical analysis

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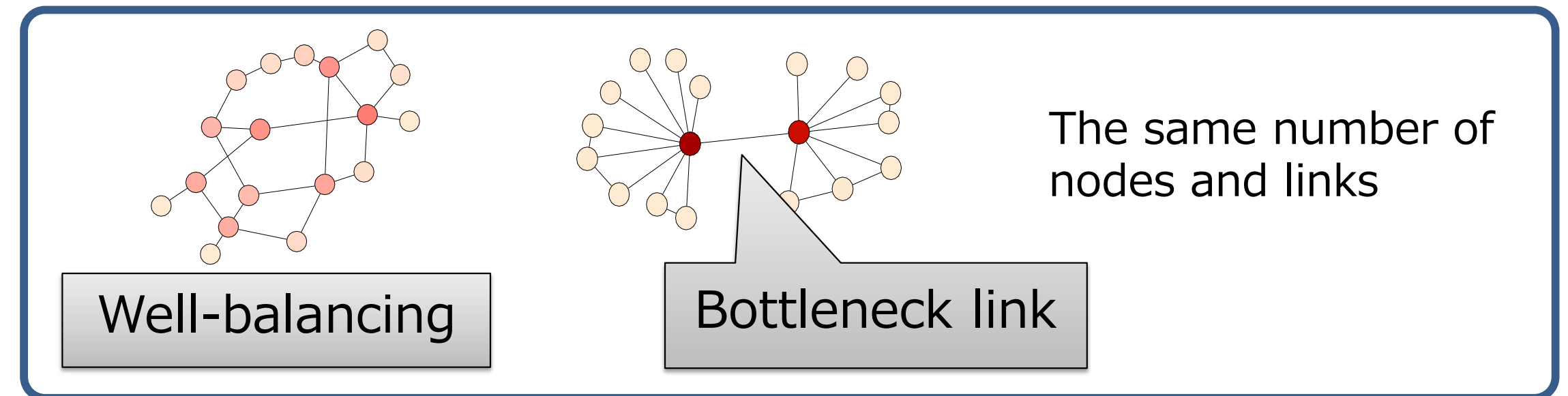
1. Background

- The Internet consists of diverse networks and links between the networks.
 - The Internet service providers, contents providers, academic networks
 - The network in the Internet is called "**AS (Autonomous System)**"
- The Internet is the one of the largest and the most complex network systems.



The structure and properties of the Internet topology is **not clear**

- Structure of topology relates to network performance.
 - Load balancing
 - Bottleneck links
 - Amount of network equipment needed to accommodate traffic demand



- The investigation of **traffic aggregation** in the Internet topology is important.
 - For performance evaluation of new applications
 - For expanding network
- The investigation of the longitudinal evolution of Internet topology is required.
 - Predicting the future structure and properties of the Internet is needed to create new applications or protocols.

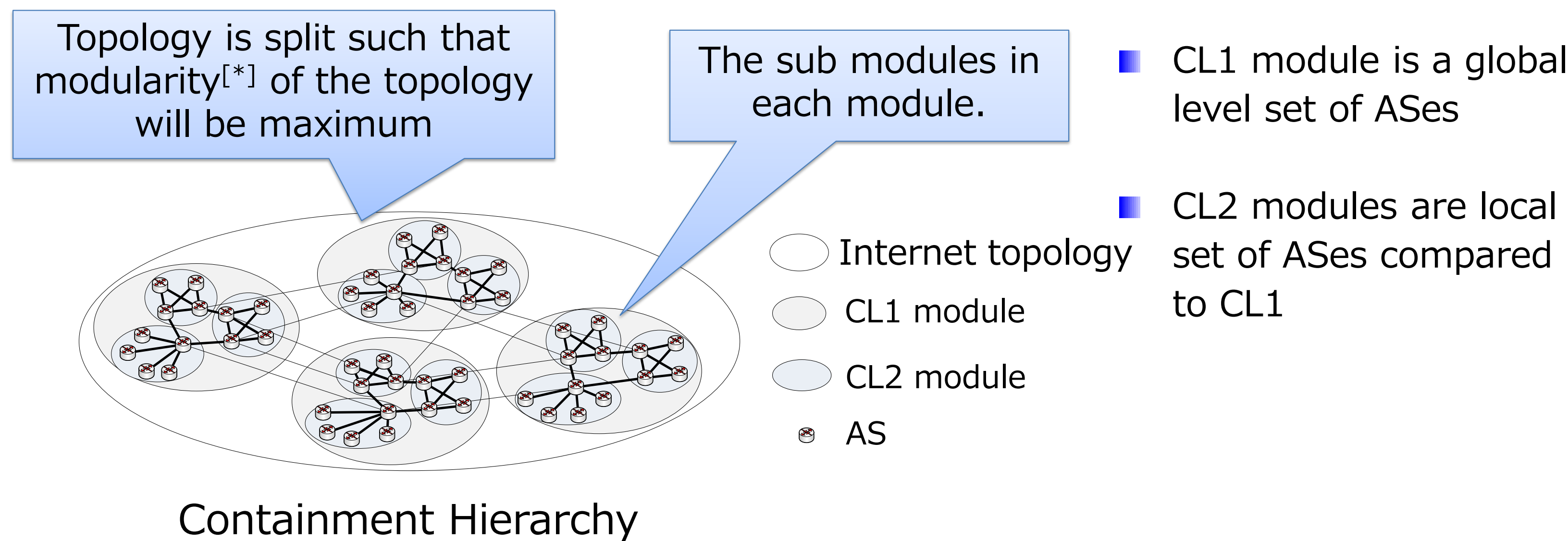
2. Goal of our research

We reveal **the evolution process of the Internet topology**

- We provide answers to below questions.
 - Where more traffic is aggregated?
 - How does the trend of traffic aggregation change?

3. Approach

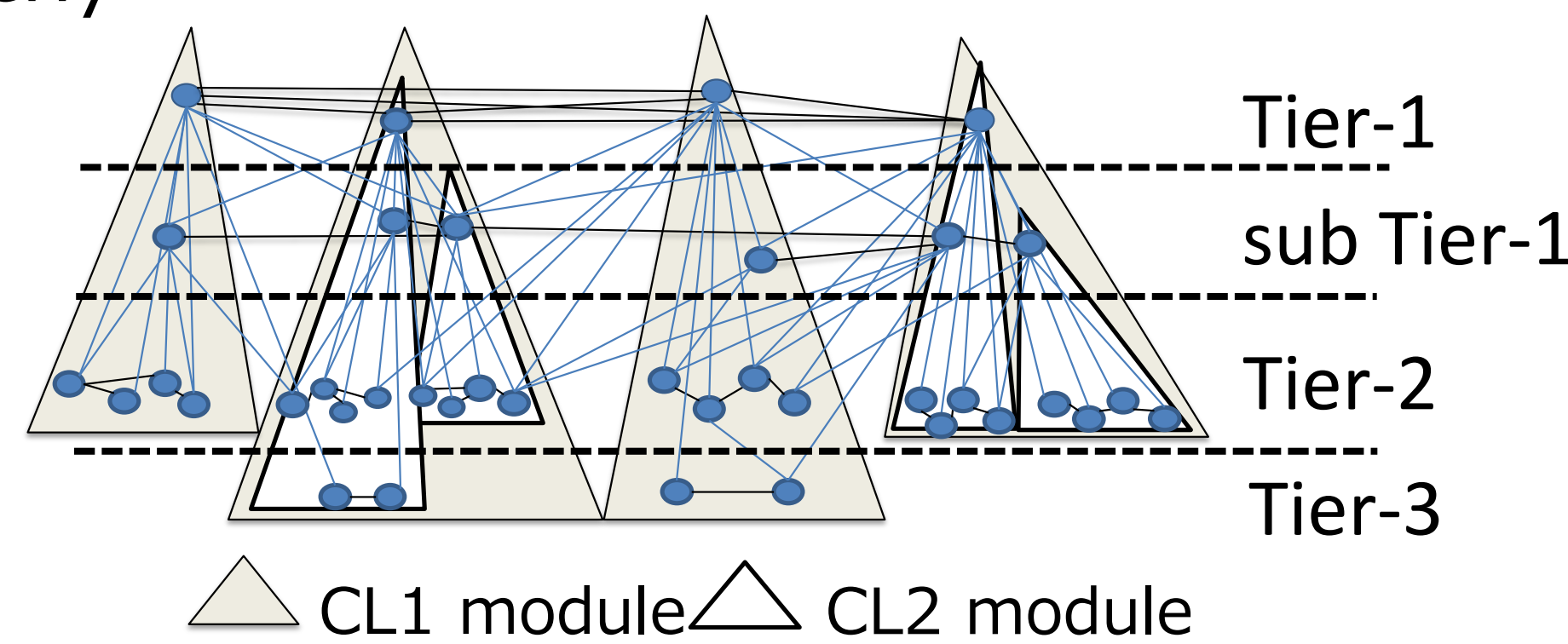
- We focus on a module defined as a set of ASes that are densely connected with many links.
 - Two or more modules are connected with (relatively) few links at which traffic is aggregated.
- We analyze evolutionary change of AS-level topology through "**Containment hierarchy**".
 - Hierarchical structure of modules
- By analyzing containment hierarchy, we show below points.
 - Hierarchy of traffic aggregation
 - Longitudinal change of traffic aggregation



[*] M. E. J. Newman and M. Girvan, "Finding and evaluating community structure in networks," Phys. Rev. E, vol. 69, p. 026113, Feb. 2004.

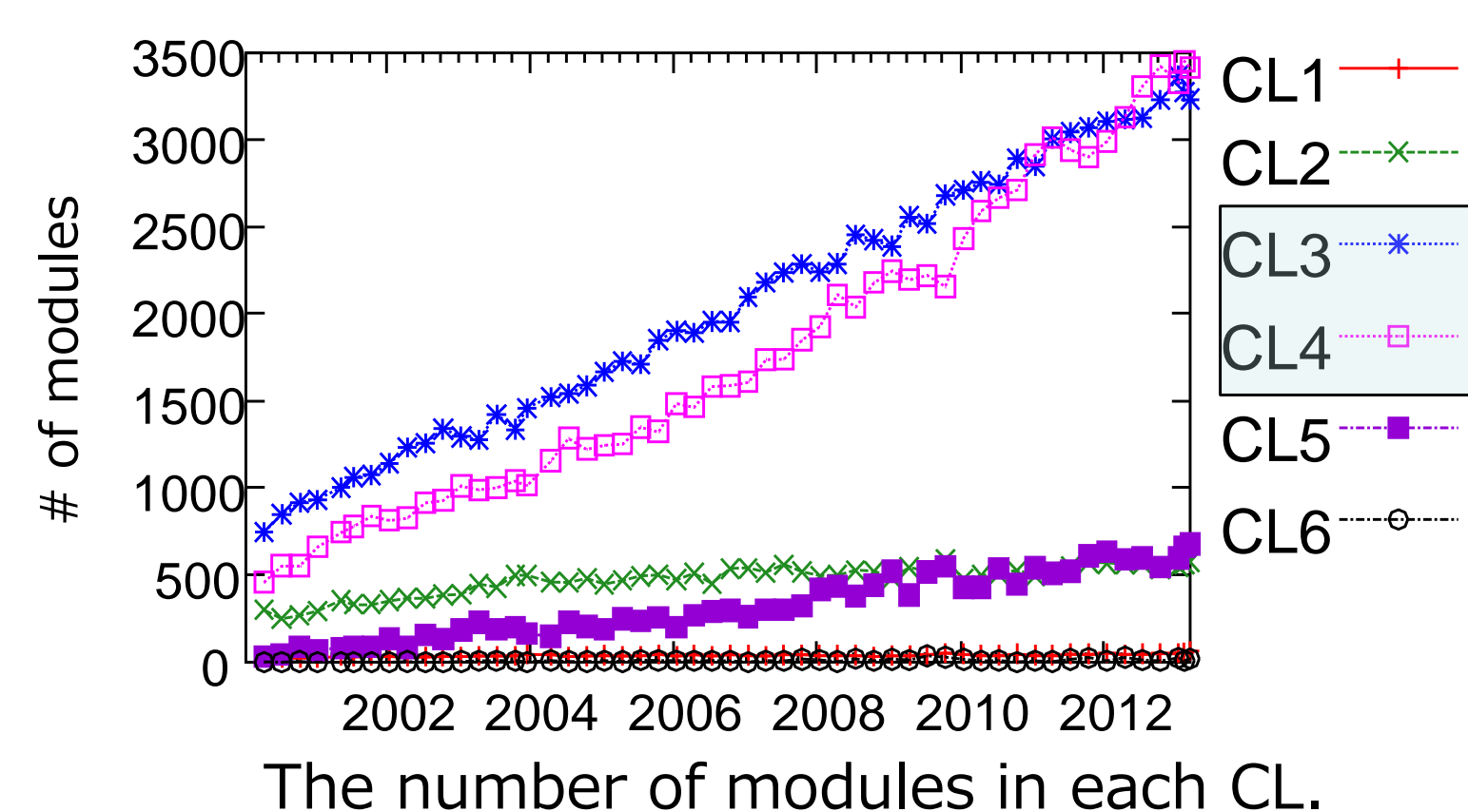
4. Analyses of the Internet topology based on containment hierarchy

- The structure of containment hierarchy
 - A module is a part of Internet topology divided vertically.
 - Each module is composed by various tiers of ASes
 - Higher tier ASes have a lot of inter-modules links
- Analyzing the change of structure in containment hierarchy
 - The number of ASes in CL1 and CL2 is rapidly increasing.
 - The maximum number of CL is 6 from 2002 to 2012, which means that the width of containment hierarchy keeps constant.
 - The number of modules in CL3 and CL4 is rapidly increasing.

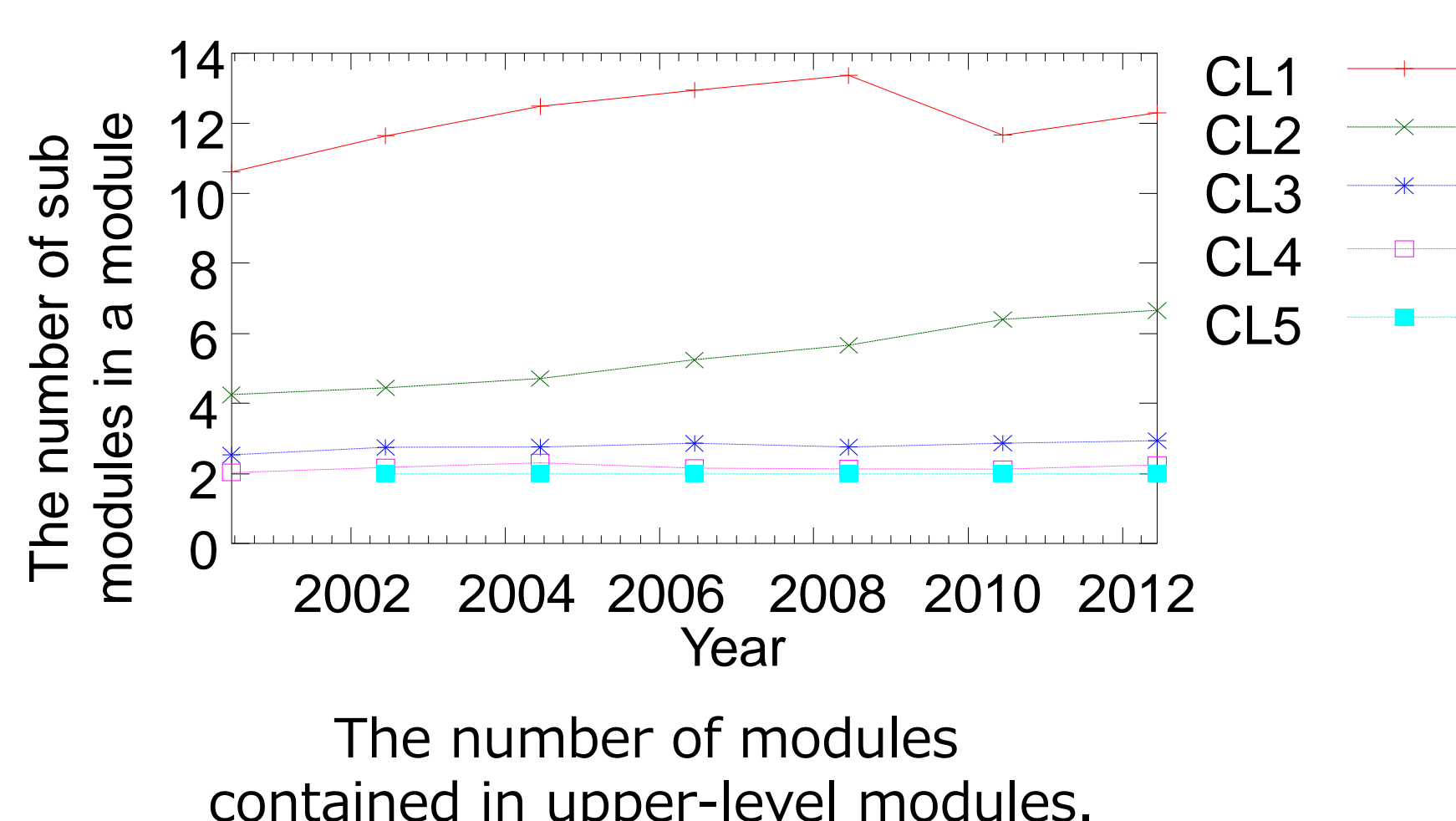


The number of modules.

Year	CL1	CL2	CL3	CL4	CL5	CL6
2000	26	255	812	529	71	0
2002	37	384	1215	881	131	6
2004	43	462	1526	1173	208	6
2006	40	479	1883	1562	299	4
2008	40	508	2437	2088	389	6
2010	42	490	2795	2641	438	2
2012	51	578	3153	3181	638	12

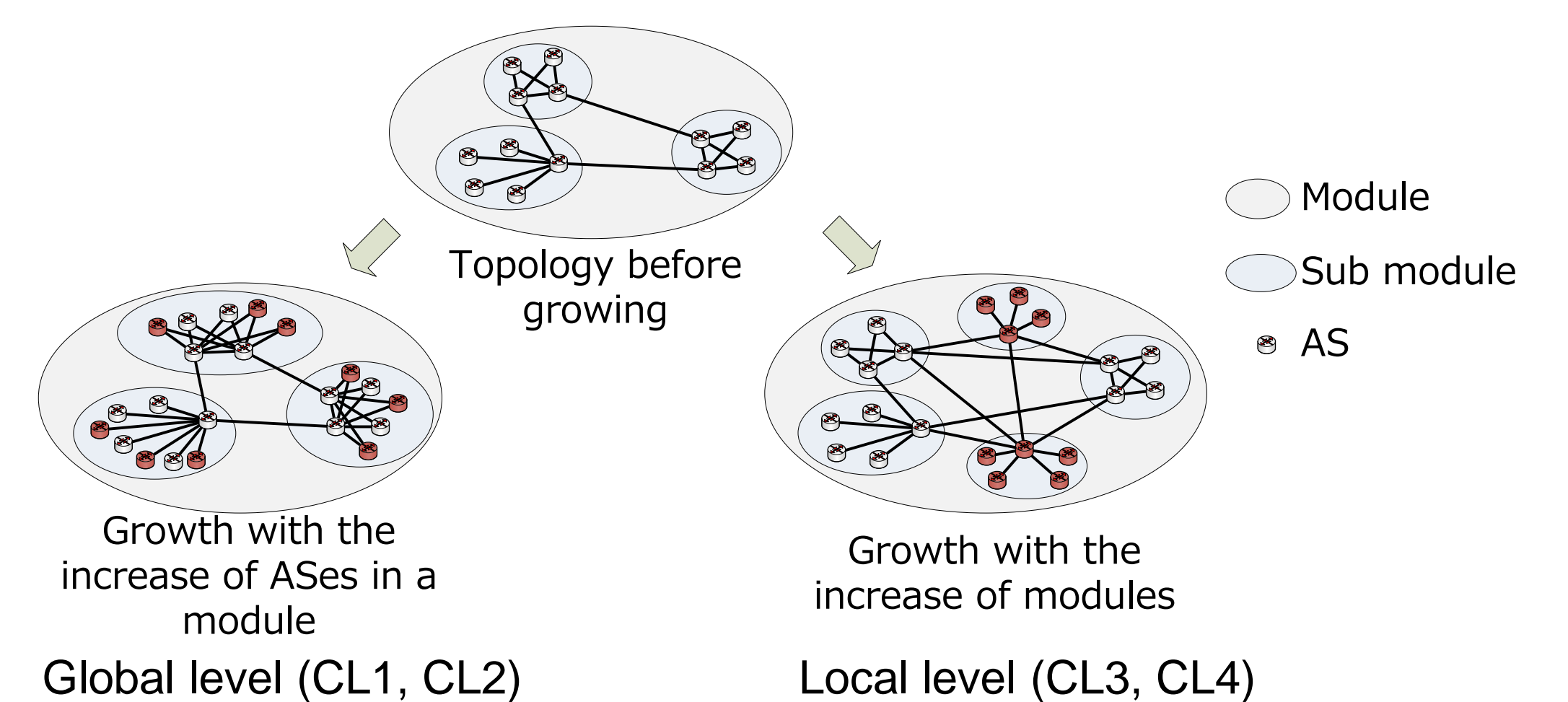


- Analyzing which inter-modules links aggregate more traffic
 - Inter-modules links aggregate traffic that is generated in sub modules.
 - We investigate the number of sub modules in a modules.
 - CL1 ⇒ increasing until 2008 and decreasing since 2008
 - CL2 ⇒ increasing constantly



5. Results of analyses and discussion

- Evolutional change of containment hierarchy
 - Global level set of ASes (CL1 and CL2) → Increase of ASes in a module
 - Local level set of ASes (CL3 and CL4) → Increase of modules



The load of traffic at inter-modules links gets heavier. Traffic aggregated at inter-modules links is distributed.

- More traffic is aggregated at CL2 inter-modules links
 - In the future, the amount of traffic traversing through a little local links rapidly increase
- The factor of the trend is the increase of inter-modules links
 - The reduction of price for constructing links
 - The increase of IX (Internet eXchange)