On Cross-Domain Data Access for Cyber-Physical-Social Systems

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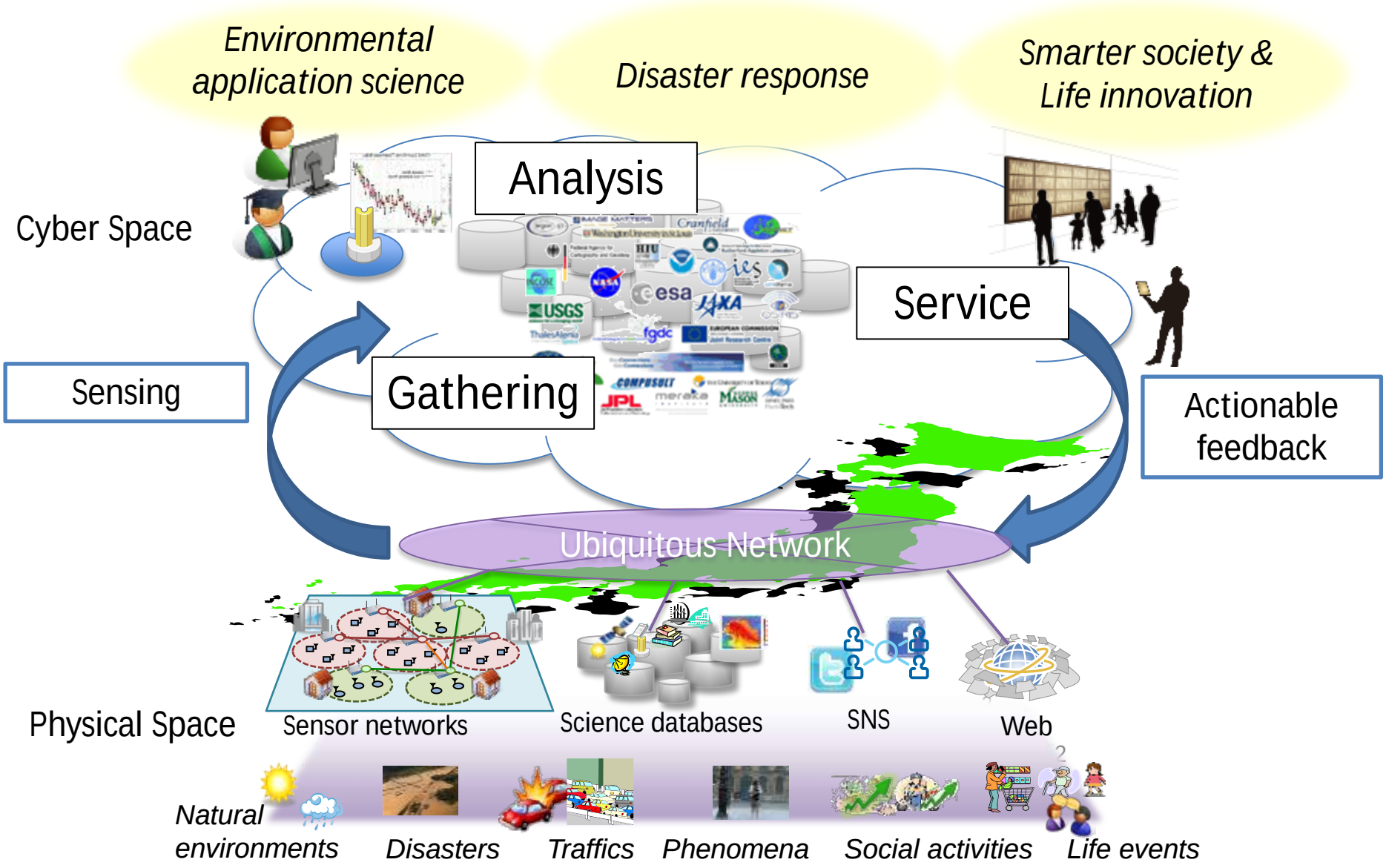
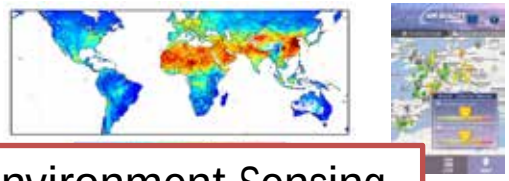
Cyber-Physical-Social Information Ecosystem



Collective Awareness of Cyber-Physical Social Event

(E.g.) PM2.5 air pollution



PM2.5 distributions

Environment Sensing

PM2.5 treatments

Profile Gathering

Locations

Sensitivities

Resource Availability

Analysis/Prediction

Individual Response

Individual Interaction

- Disaster response communities
- Social healthcare

Disaster risk analysis

- Climate influences
- Health influences

Recommendation

Action/Advice

Social Response

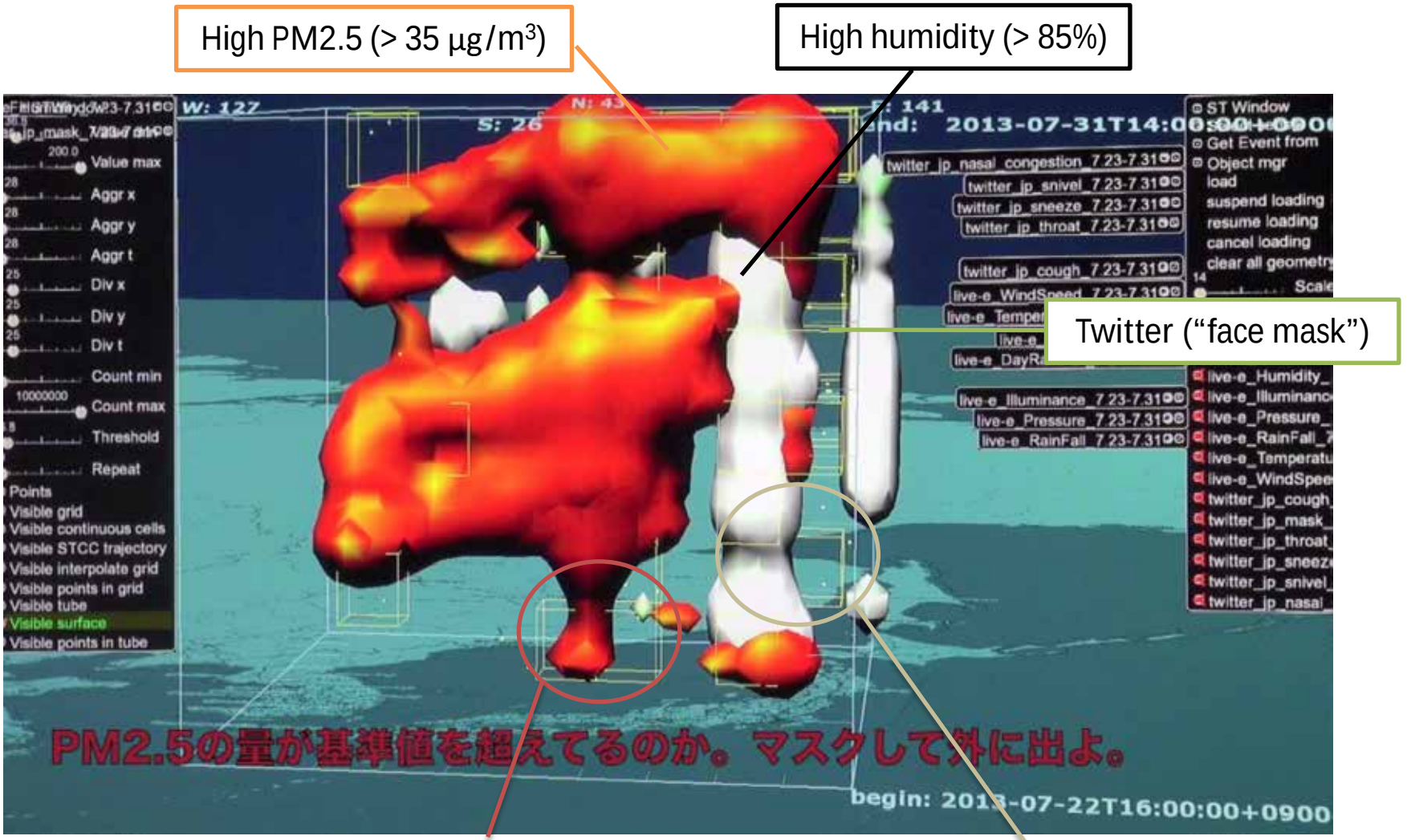
Courtesy: Event information management system (UC Irvine, NICT, 2013)

Cyber-Physical Social System: A Vision

Recognize evolving complex situations at particular location over period of time, then provide actionable feedback to device, people, and society

Model and manipulate **cyber-physical-social events** based on **'correlations'** between individually-disseminated, heterogeneous sensor data

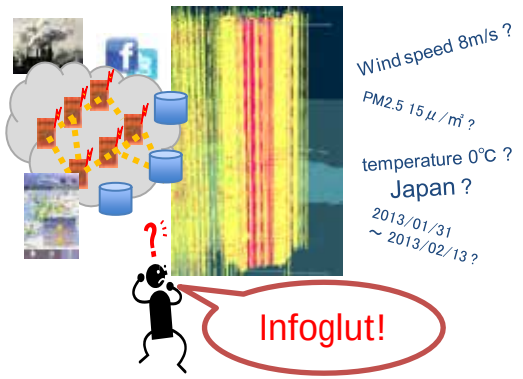
Analyzing Spatial-Temporal-Thematic Correlations



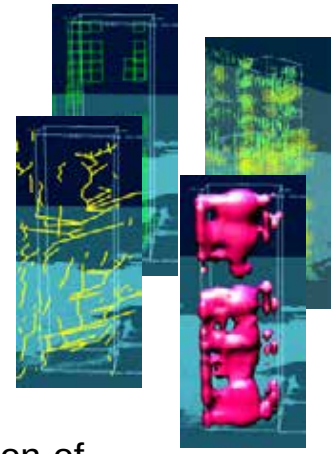
“I need to ware face mask, because PM2.5 increases extraordinarily”

“Wearing face mask makes my face smaller in such a humid day”

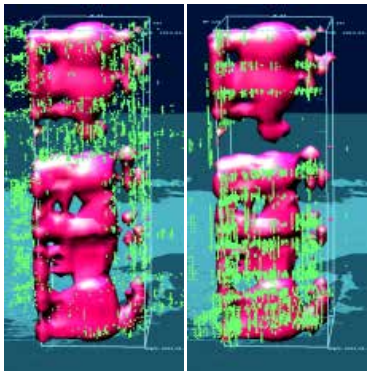
STICKER Spatio-Temporal Information Clustering and Knowledge ExtRaction



Visual correlation mining of heterogeneous sensor data in spatial-temporal-thematic (STT) space

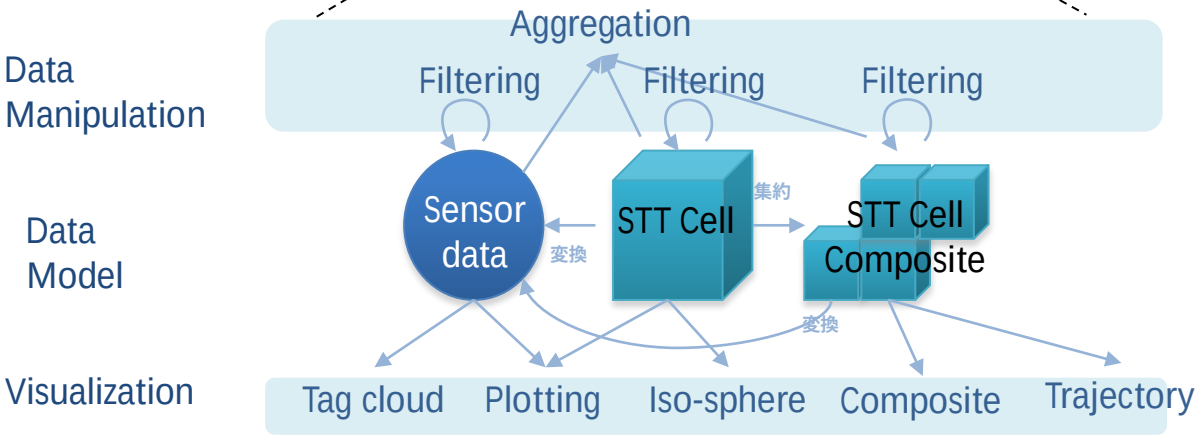


- Discover correlating dataset
- Narrow STT conditions

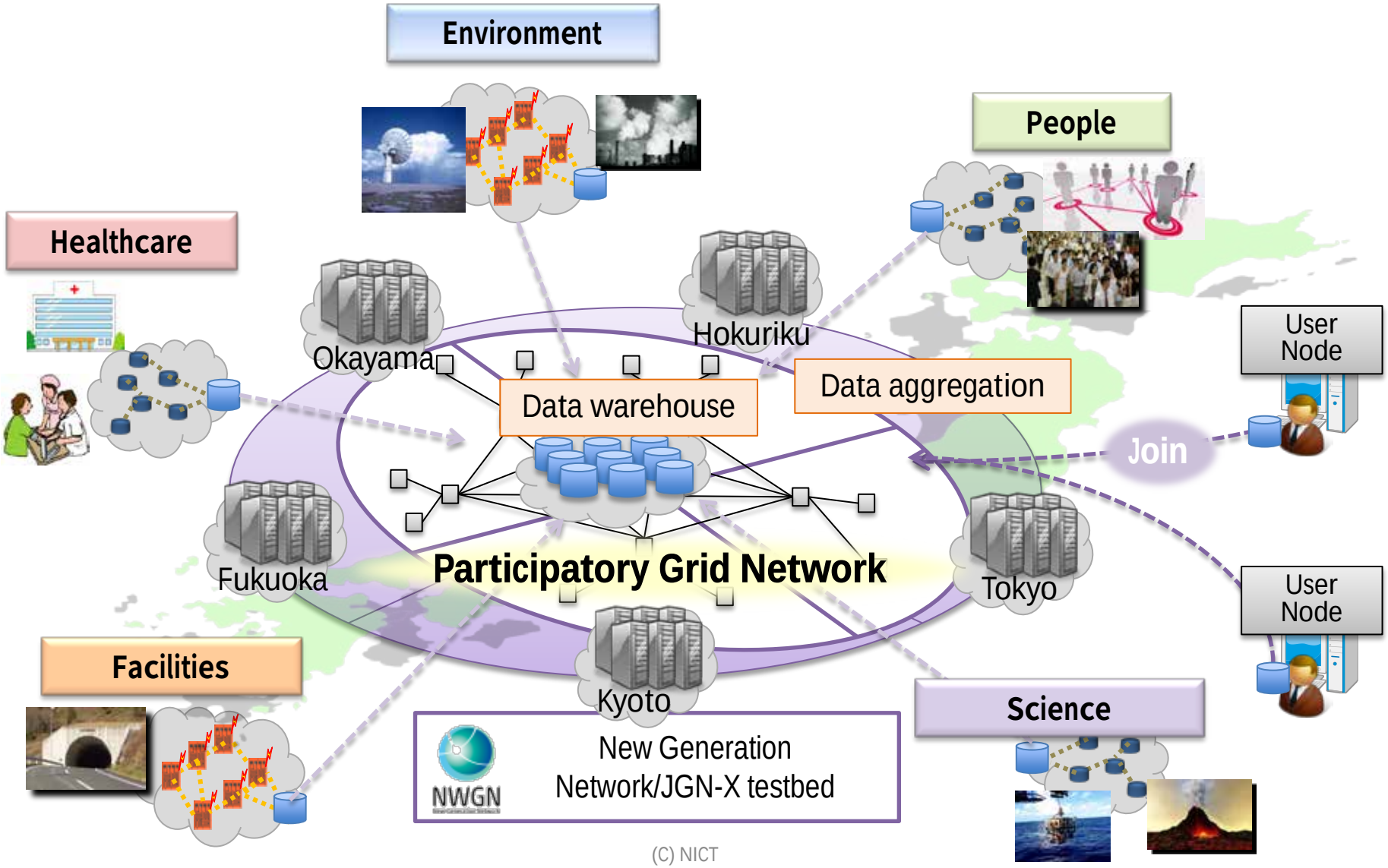


Visual presentation of movements and continuity

Visual analysis of STT correlations
intersection, surrounding, synchronization, complement, etc.



NICT K-L Grid: Cyber-Physical Social Sensing Platform

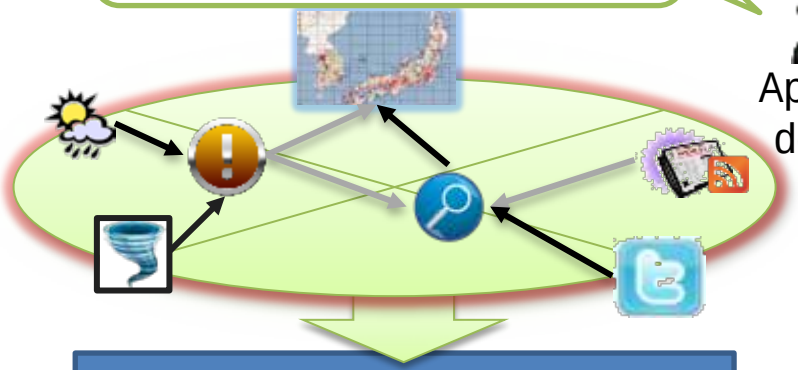


Sensing Platform Issue

- Sudden deluge of data from anonymous sources
- Ad-hoc sensing and trial-error analysis
- Quick response to ongoing situation changes

Collective sensing application

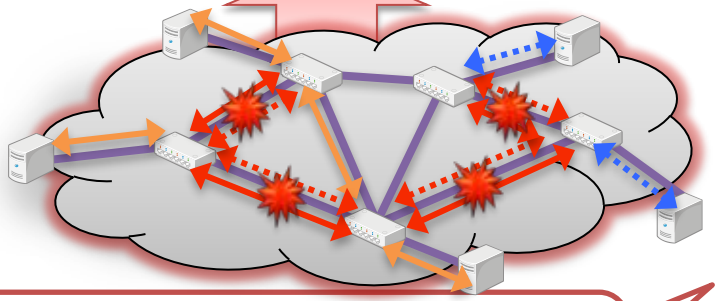
Agile gathering, processing and archiving of heterogeneous sensor data



Application developer

On-demand creation of application-specific virtual sensor networks

Physical networks



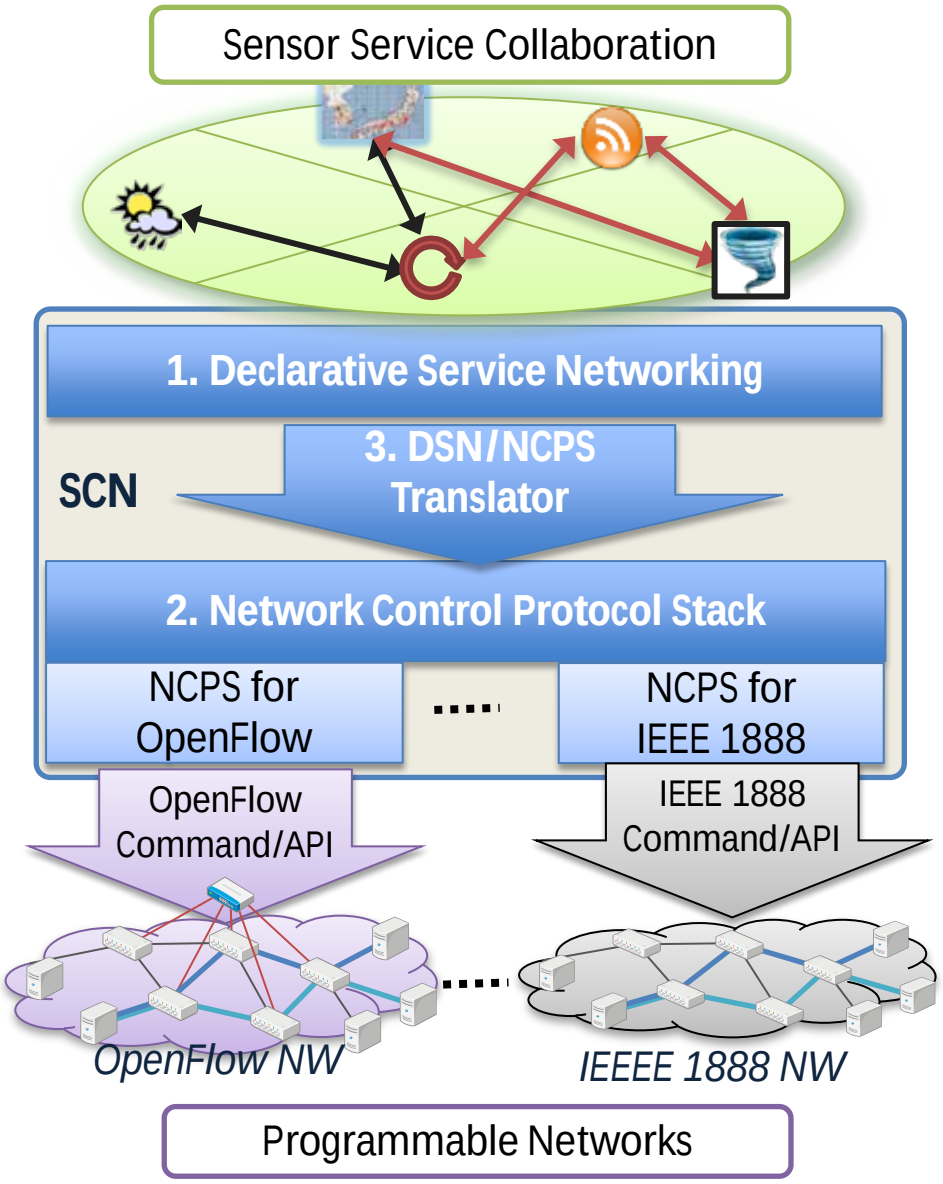
- Suffer from unforeseen traffics
- Hard to reconfigure existing sensor networks

Network administrator

Cyber-Physical-Social Sensor Service (CPSenS)

- Sensor Service Collaboration Overlay
  - ***Sensor virtualization*:** encapsulates data sources as *sensor services*
  - ***Vertical sensor integration*:** combines heterogeneous sensor services on demand
  - ***Horizontal sensor integration*:** complements missing data with multiple sensors

- Service Controlled Networking (SCN)
  1. **Declarative Service Networking (DSN):** defines application-specific sensor service collaboration by declarative rule language
  2. **Network Control Protocol Stack (NCPS):** Invoke programmable network commands for dynamic configuration; service node discovery, path setting, status monitoring
  3. **DSN/NCPS Translator:** Generate NCPS commands by interpreting DSN descriptions with multiple-overlay coordination



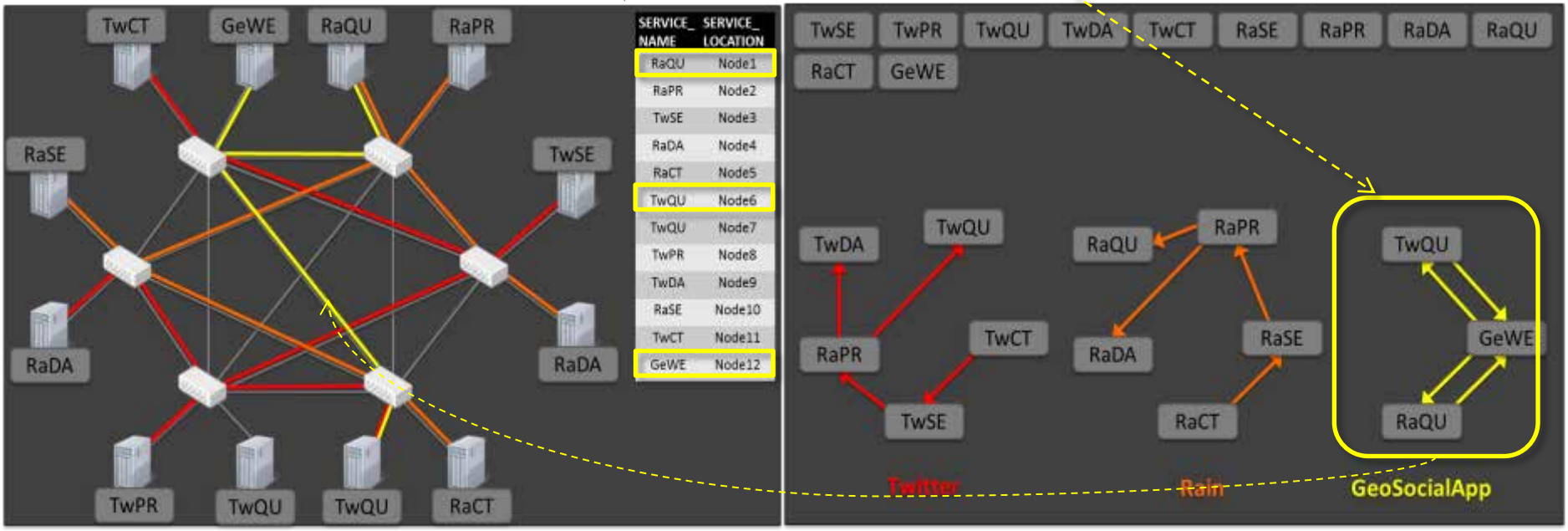
CPSenS Example

DSN description

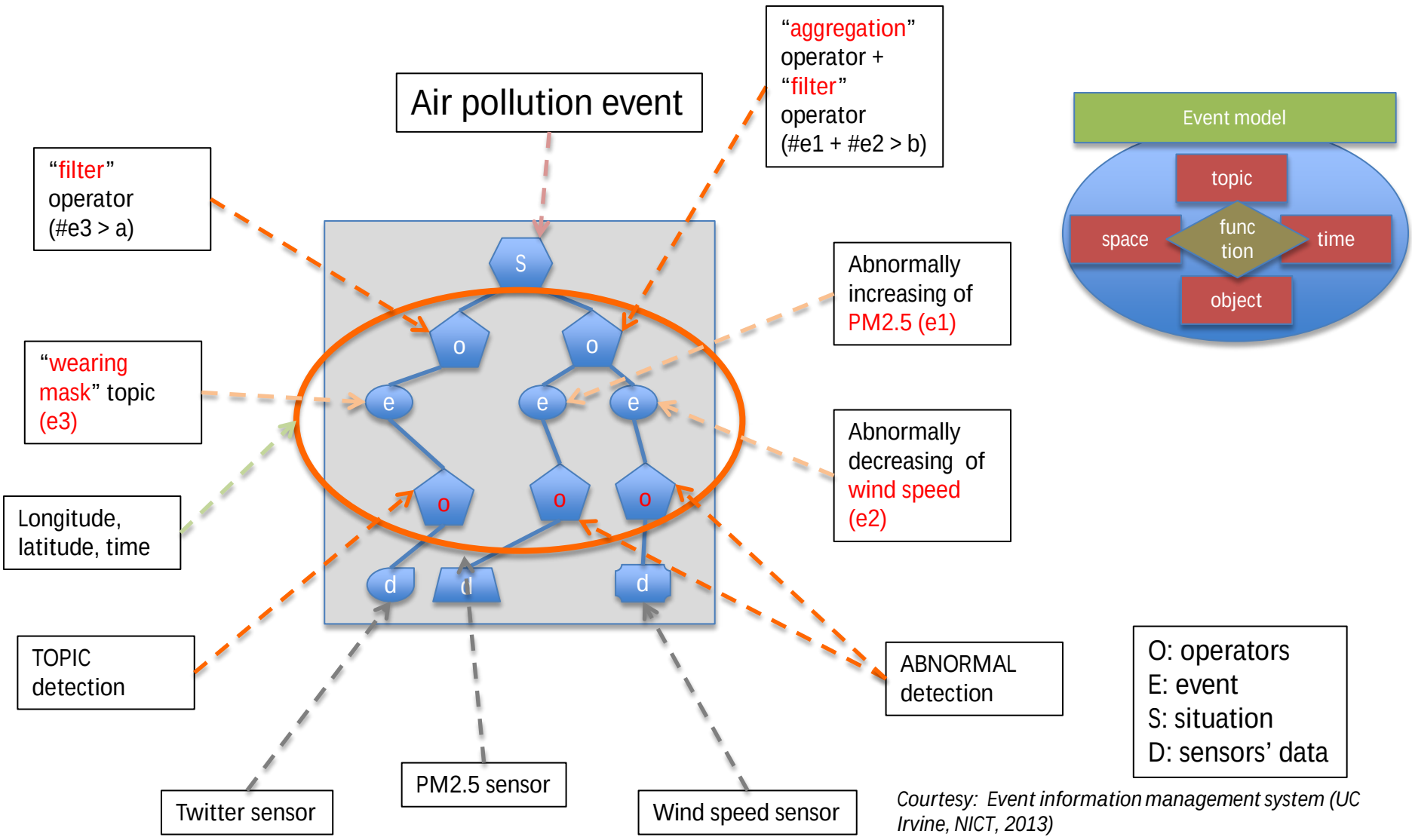
```
Overlay GeoSocialApp
// 1. Service registration
R1 REGIST(GeWE) <~ IDENT(GeoSocialWeb, GeWE, “192.168.94.62”)
// 2. Service search
F1 FIND(RaQU) <~ REQUEST(GeWE, RaQU)
F2 FIND(TwQU) <~ REQUEST(GeWE, TwQU)
// 3. Path creation and message exchange
S1 SEND(GeWE, RaQU, “50 <= Rain” & “1000 < SampleRate”) <~ FIND(RaQU)
S2 SEND(GeWE, TwQU, “disaster” & “4000 < Record”) <~ FIND(TwQU)
```

Sensor service collaboration

OpenFlow paths by NCPS



Seamless Processing form Sensor Data to Complex Event



Courtesy: Event information management system (UC Irvine, NICT, 2013)

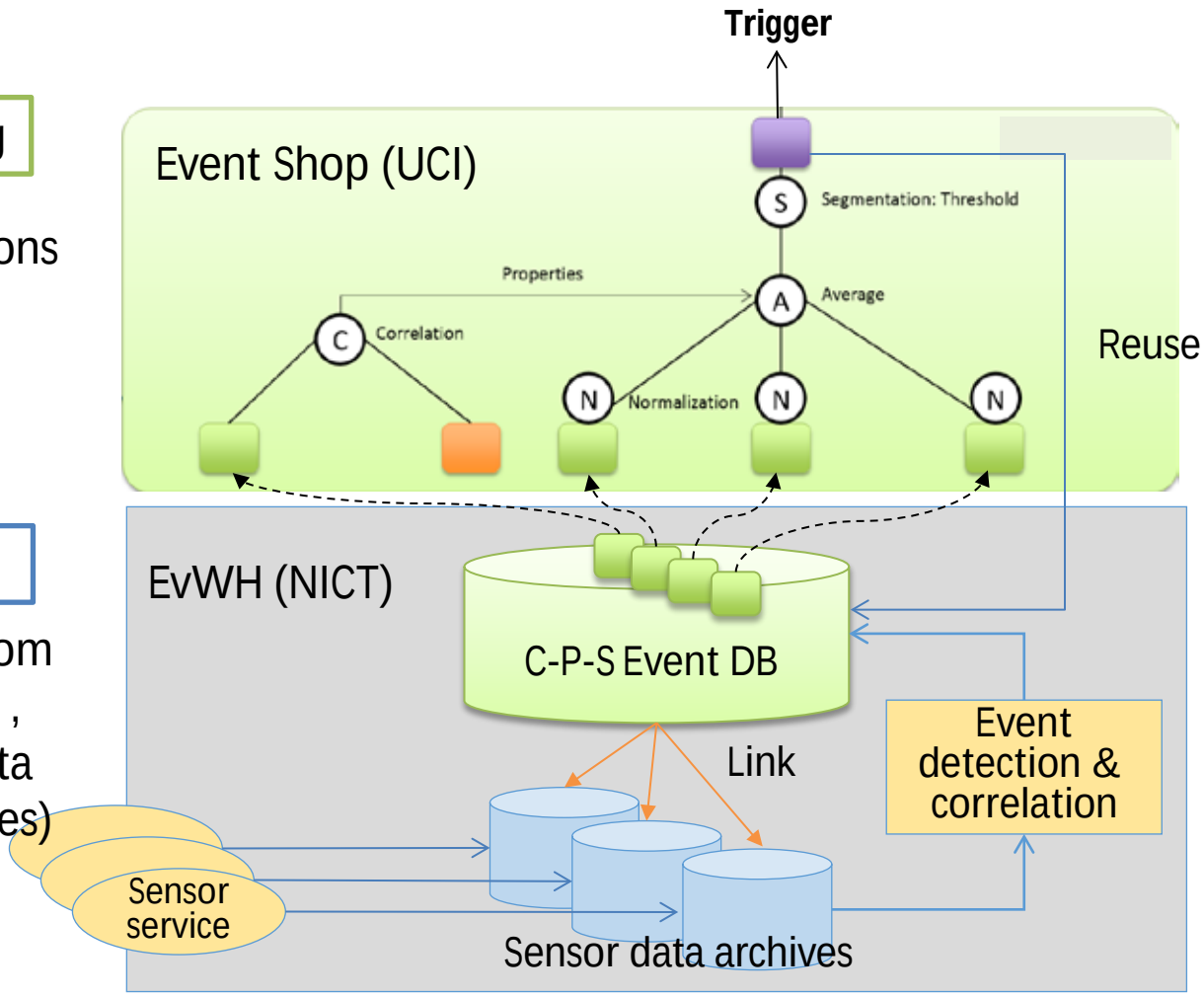
Event Information Management System

Complex event processing

Analyzing complex situations by spatio-temporal event stream processing

Event Warehousing

Creating atomic events from individually-disseminated , heterogeneous sensor data (both streams and archives)



Courtesy: Event information management system (UC Irvine, NICT, 2013)

Event Warehouse (EvWH)

Correlation Database (Value-based Storage approach)

Weather sensor data

Timestamp	Station	Temperature	precipitation
2012-03-01 11:02:35	AP-Kyoto	2.1 C	3.5mm
2012-03-01 11:03:05	AP-Tokyo	11.2C	0.1 mm
2012-03-01 11:03:35	AP-Osaka	1.0C	2.1mm

SNS sensor data (weather topic)

Datetime	Geotag	#Tag	Text
2012-03-01 11:00:02	35.011636, 135.768029	#Weather	Wondering if it snows
2012-03-01 11:02:00	35.681382, 139.766084	# Weather	Spring has come
2012-03-01 11:05:45	34.701909, 135.494977	#Weather	Not good for laundry

Data values
tag:value

1:2012-03-01 11:02:35,
2:2012-03-01 11:03:05,
3:2012-03-01 11:03:35,
4:AP-Kyoto,
5:AP-Tokyo,
6:2.1C,
7:11.2C,
8:1.0C,
9:3.5mm,
10:0.1mm,
11:2.1mm

Table structure
record_tag:[tag, tag,...],

1001:[1, 4, 6, 9],
1002: [2, 5, 7, 10],
1003:[3, 4, 8, 11]

Data values
tag:value

21:2012-03-01 11:00:02,
22:2012-03-01 11:02:00,
23:2012-03-01 11:05:45,
24:35.011636, 135.768029,
25:35.681382, 139.766084 ,
26:34.701909, 135.494977,
27:#Weather,
28: Wondering if it snows,
29: Spring has come,
30: Not good for laundry

Table structure
record_tag:[tag, tag,...],

2001:[21, 24, 27, 28],
2002: [22, 25, 27, 29],
2003:[23, 26, 27, 30]

Ontological correlation (metrology)

Ontological correlation (Atmosphere)

Spatiotemporal correlation

Correlation *corr_tag: (tag, tag, ..)/corr_coeff ... corr_label*

101: (1, 2, 3, 21, 22, 23)/0.95 ... *[2012-03-01 noon]*
102: (4, 24, 26)/ 0.92 ... *Kansai area*
103: (5, 25)/0.80 ... *Tokyo area*
104: (6, 8, 9, 11)/0.85 ... *snow*
105: (7, 10)/0.9 ... *sunny*
106: (28, 30)/0.6 ... *cheerless day*

JOIN over Correlation

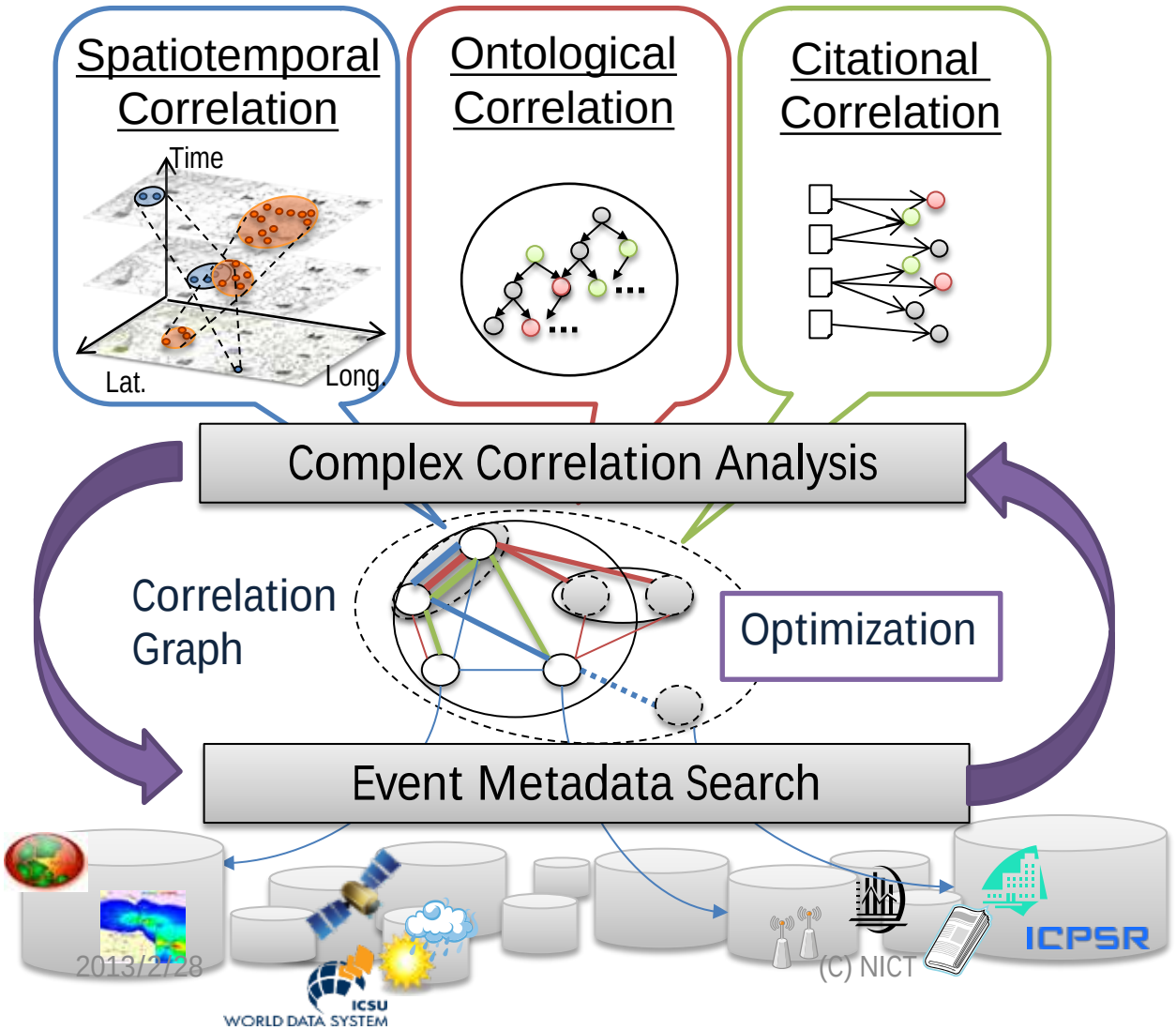
Table structure
record_tag:[tag/certanty, tag/certainty,...],)

5001:[101/0.95, 102/0.92, 104/0.85, 106/0.6,],
5002: [101/0.95, 103/0.80, 105/0.9, 29:/1.0]

Period	Area	Weather	Atmosphere
101/0.95: [2012-03-01 noon]	102/0.92: Kyoto area	104/0.85: snow	106/0.6: cheerless day
101/0.95: [2012-03-01 noon]	103/0.80: Tokyo area	105/0.9: sunny	29: Spring has come

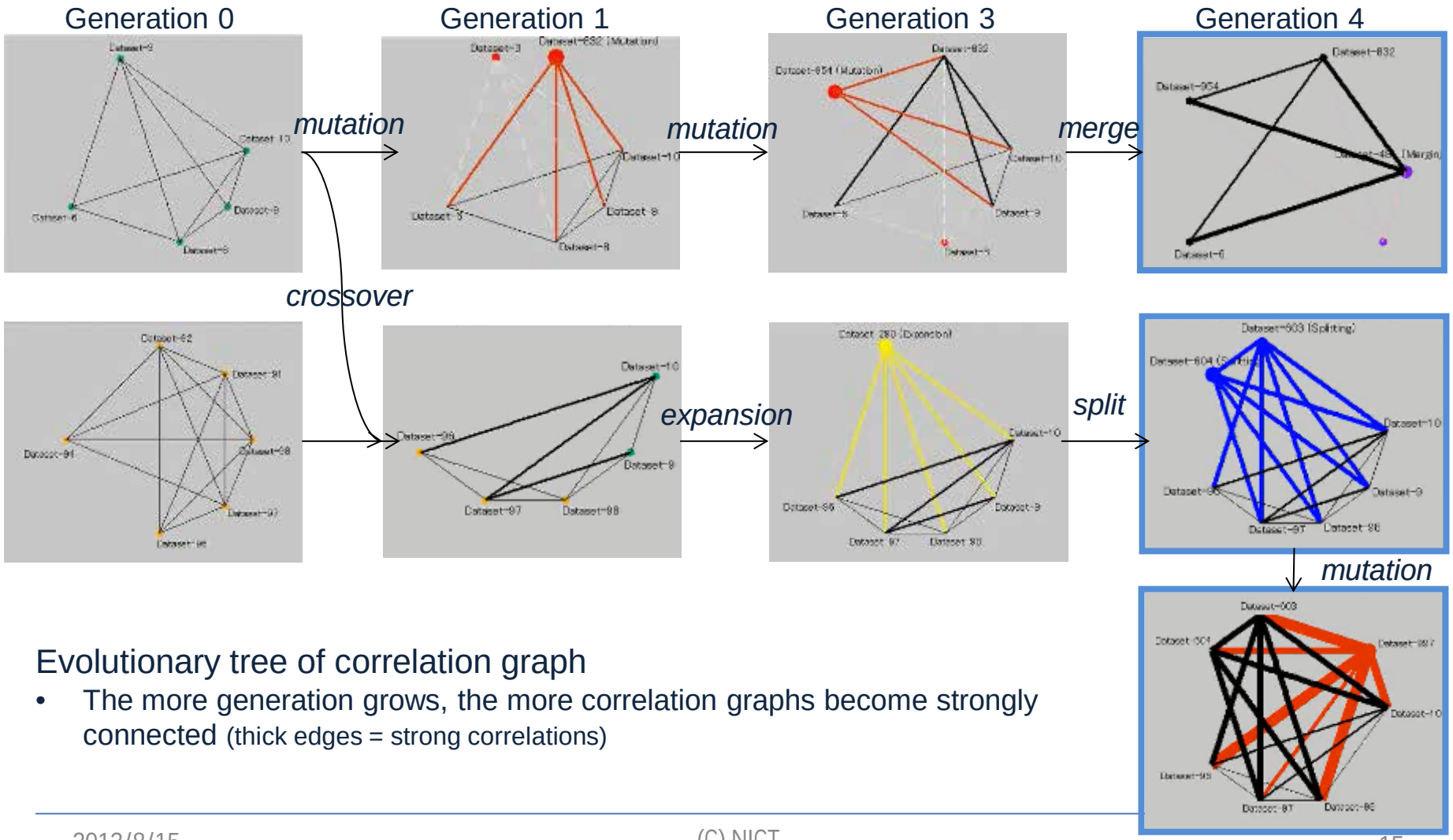
Cyber-Physical-Social Event

Correlation Search (Cross-DB Search)



Correlation Clustering by Evolutional Computing

- Optimize correlation graph cluster by evolutional operations: *merge, split, expansion, crossover,* and *mutation*



Evolutionary tree of correlation graph

- The more generation grows, the more correlation graphs become strongly connected (thick edges = strong correlations)

Example of Cross-DB Search

Query：“ice sheet” in Northern Hemisphere

Select spatially- and ontologically-correlating data

Examples of added dataset

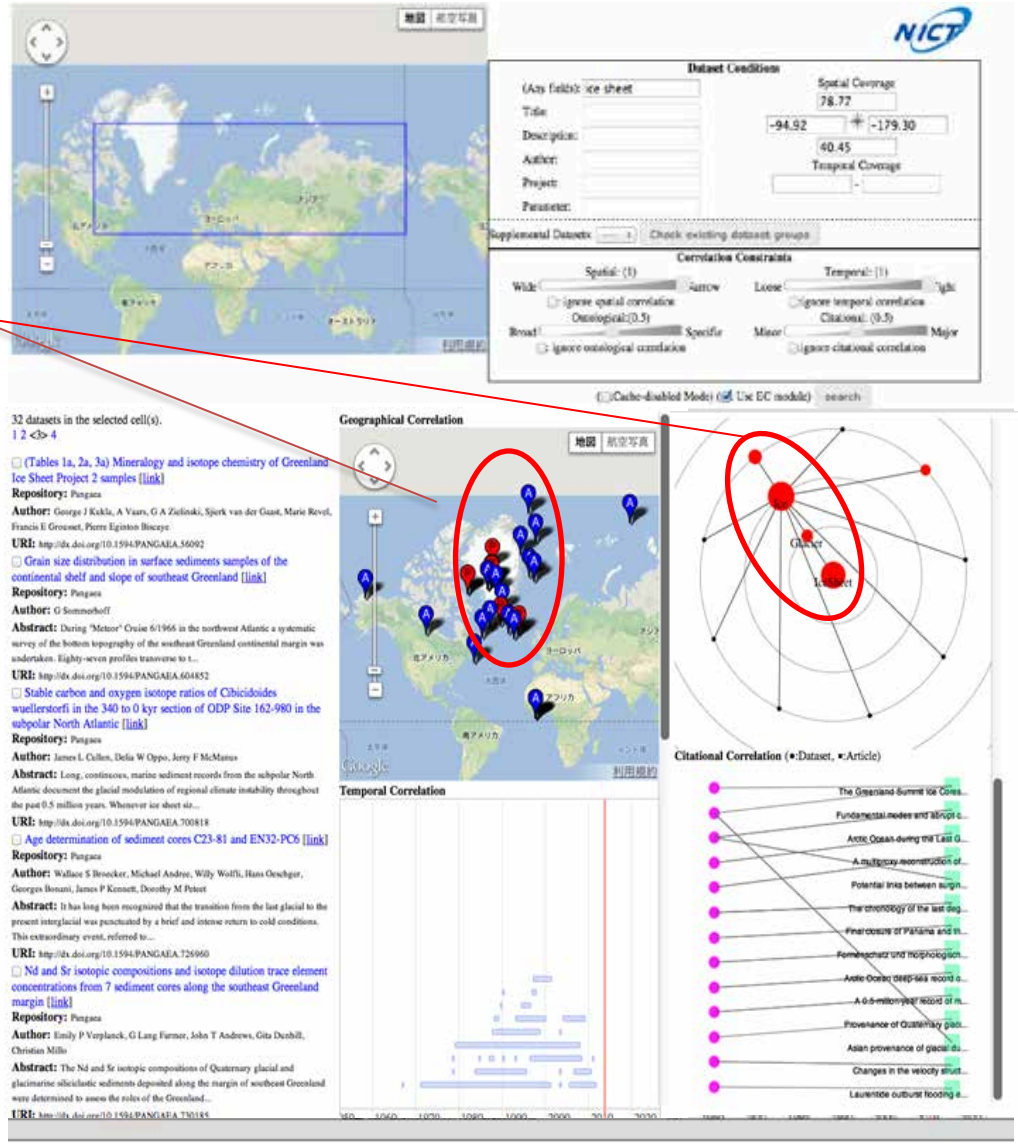
Arkhipov, SM (2000): Chemistry of ice core FRD79. doi:10.1594/PANGAEA.56202,
In: **Arkhipov, Serguei M; Kotlyakov, Vladimir; Punning, Ya-M K; Zogorodnov, V; Nikolayev, V I; Zagorodnov, V S; Macheret, Yu Ya; Vaikmaye, R; Barkov, N I; Korsun, SA; Korotkevich, V; Morev, V A; Evseyev, A V; Vostokova, T A; Andreev, Andrei A; Klementyev, Oleg L; Korotkevitch, YS; Stiévenard, Michel; Sinkevich, SA; Samoylov, O Yu; Gordienko, FG; Korsun, AV; Tiugu, KR; Arkipov, SM (2008):** Deep drilling of glaciers: Russian projects in the Arctic (1975-1995). *Institute of Geography, Russian Academy of Sciences, Moscow*, doi:10.1594/PANGAEA.707363

Wasilowska, Agnieszka; Rzepecki, Marek (2010): Hydrochemistry and pigments measured on water bottle samples at Admiralty Bay in 2007. *Department of Antarctic Biology, Polish Academy of Sciences*, doi:10.1594/PANGAEA.740077

Impact of climate induced glacier melt on marine coastal systems, Antarctica (IMCOAST)

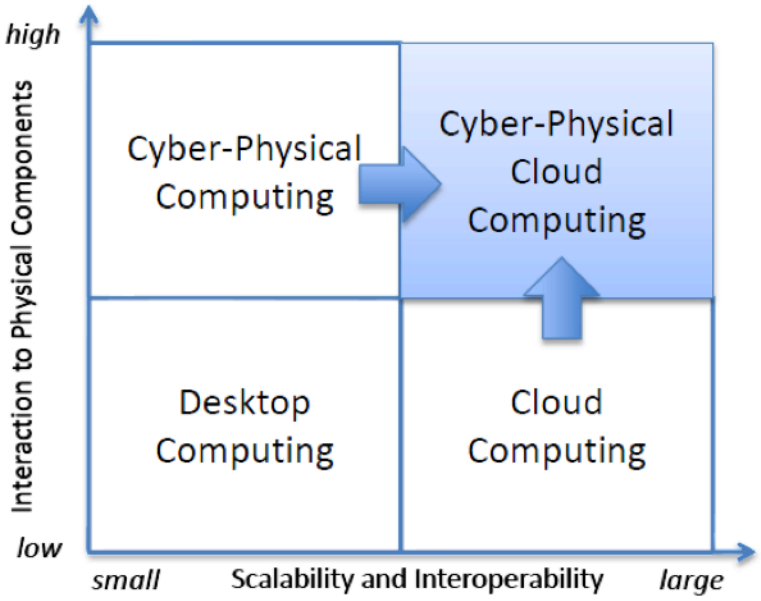
Klages, JP et al. (2013): Clay mineral content of sediment core PS75/234-1. doi:10.1594/PANGAEA.779835,
In Supplement to: **Klages, Johann Philipp; Kuhn, Gerhard; Hillenbrand, Claus-Dieter; Graham, Alastair GC; Smith, James A; Larter, Robert D; Gohl, Karsten (2013):** First geomorphological record and glacial history of an inter ice stream ridge on the West Antarctic continental shelf. *Quaternary Science Reviews*, 61, 47-61, doi:10.1016/j.quascirev.2012.11.007

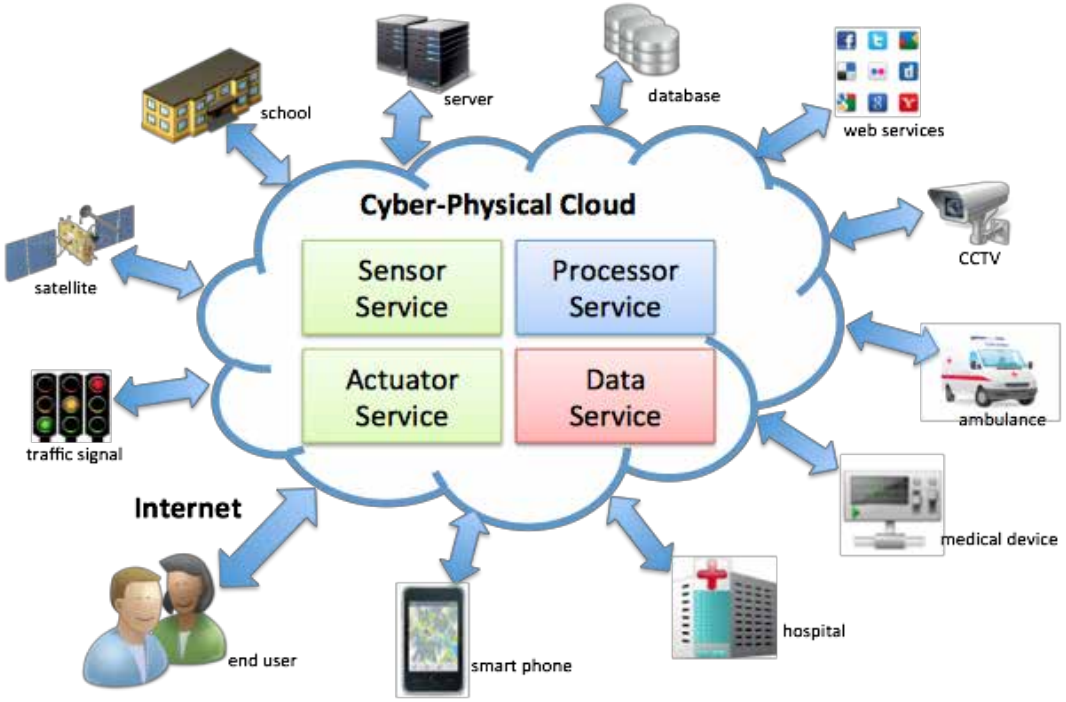
Paleoenvironmental Reconstructions from Marine Sediments @ AWI (AWI_Paleo)



Towards Cyber-Physical Cloud Computing

Cyber-Physical Cloud Computing (CPCC) is defined as: "*a system environment that can rapidly build, modify and provision auto-scale cyber-physical systems composed of a set of cloud computing based sensor, processing, control, and data services*".

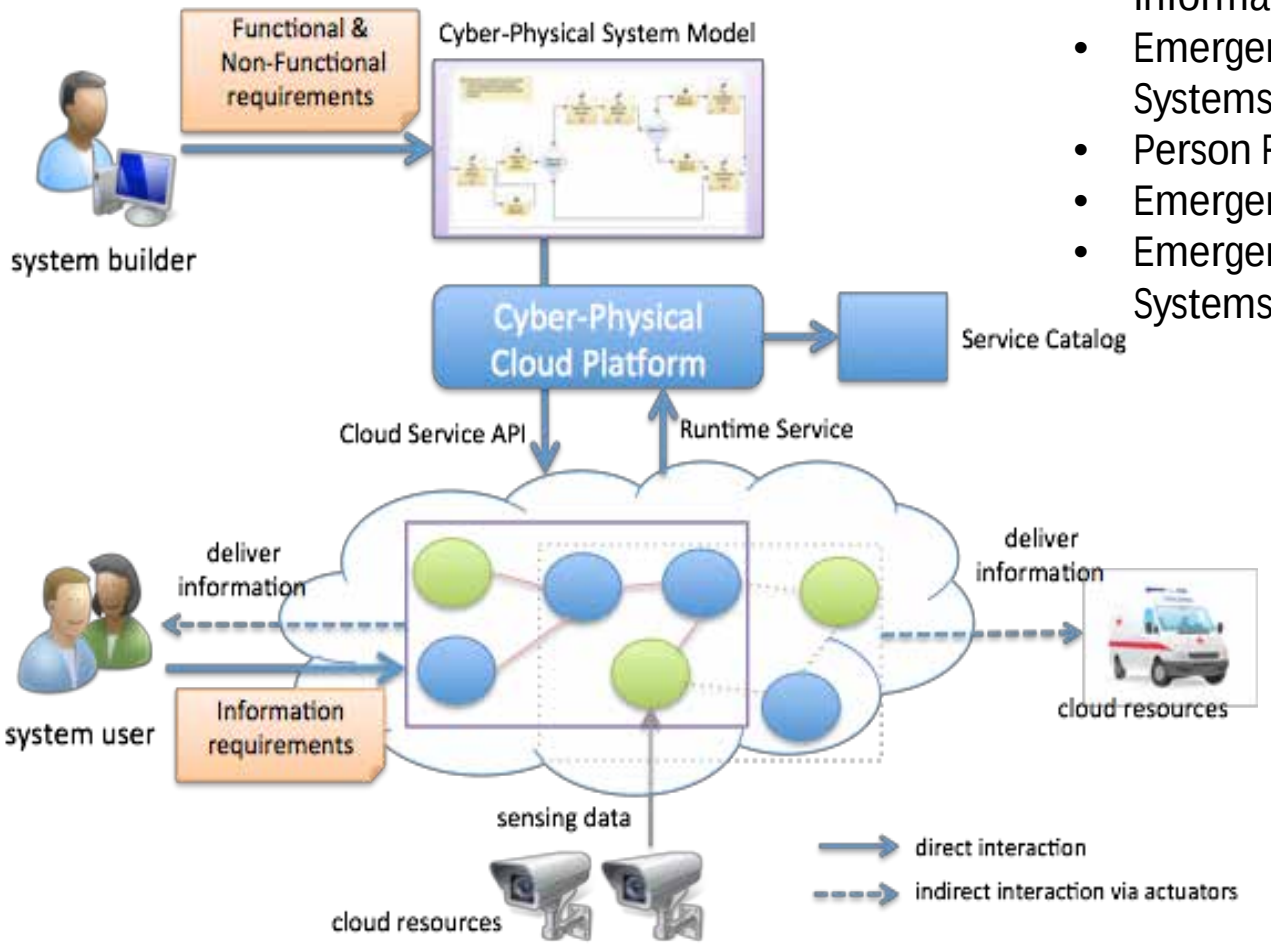




- Efficient use of resources
- Modular composition
- Rapid development and scalability of cyber-physical systems
- Smart adaptation to environment at every scale
- Scalable reliability and performance

Reference: Cyber-Physical Cloud: its Roots, Architecture, Challenges and Opportunities (NICT, NIST, 2013)

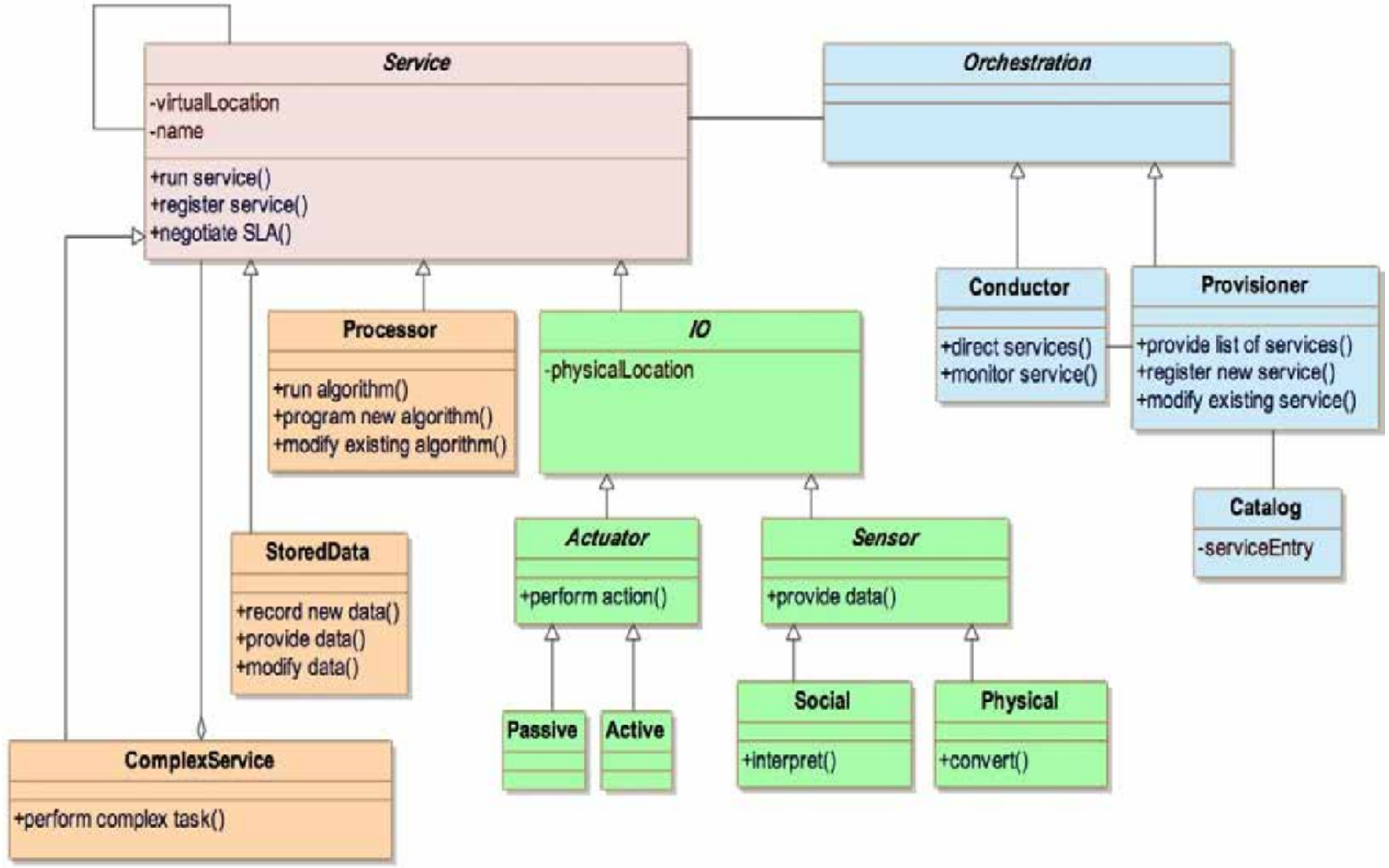
CPCC Scenario



- Geo-Fencing: deliver local information from global monitoring
- Emergency Evacuation and Rescue Systems
- Person Find Systems
- Emergency Health Care Systems
- Emergency Telecommunication Systems

Reference: Cyber-Physical Cloud: its Roots, Architecture, Challenges and Opportunities (NICT, NIST, 2013)

CPCC Conceptual Architecture



Reference: Cyber-Physical Cloud: its Roots, Architecture, Challenges and Opportunities (NICT, NIST, 2013)

Conclusions

Event-specific collaboration

Scalable C-P-S system

Event-oriented collaboration