High Performance Computing, Cloud computing, and Remote Sensing Big Data

Lizhe Wang

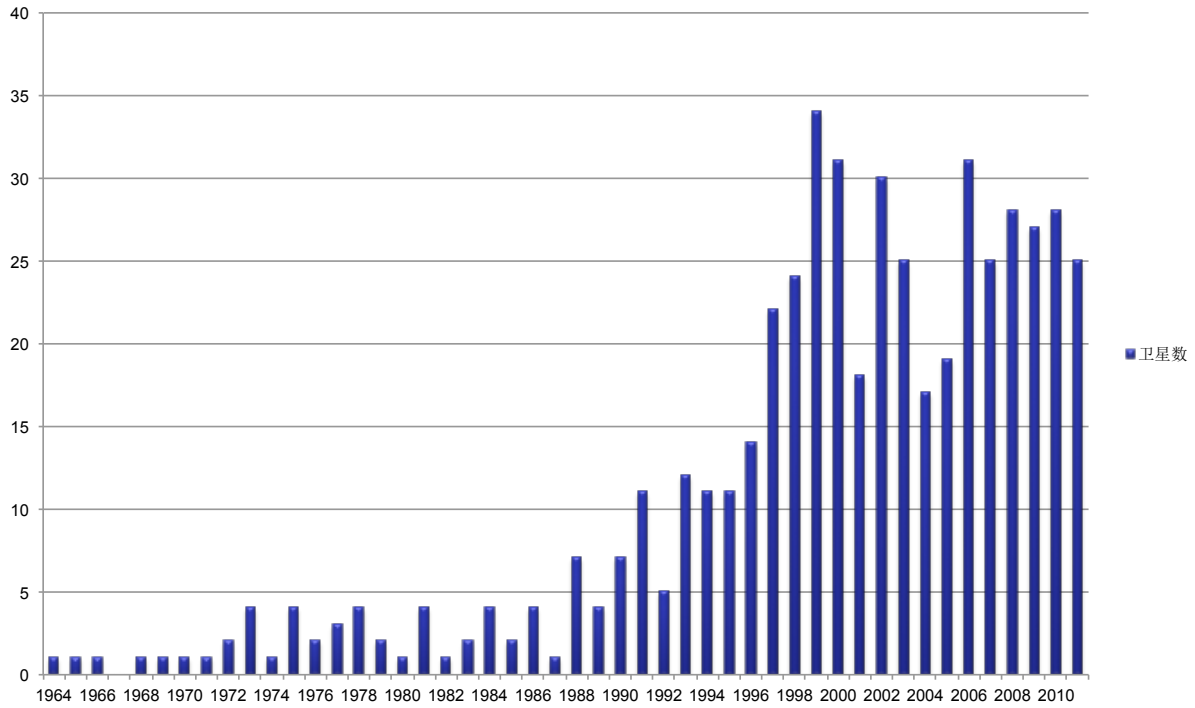
Institute of Remote Sensing and Digital Earth (RADI)
Chinese Academy of Sciences (CAS)
email: Lizhe.Wang@computer.org

March 2016, Canberra, Australia

Contents

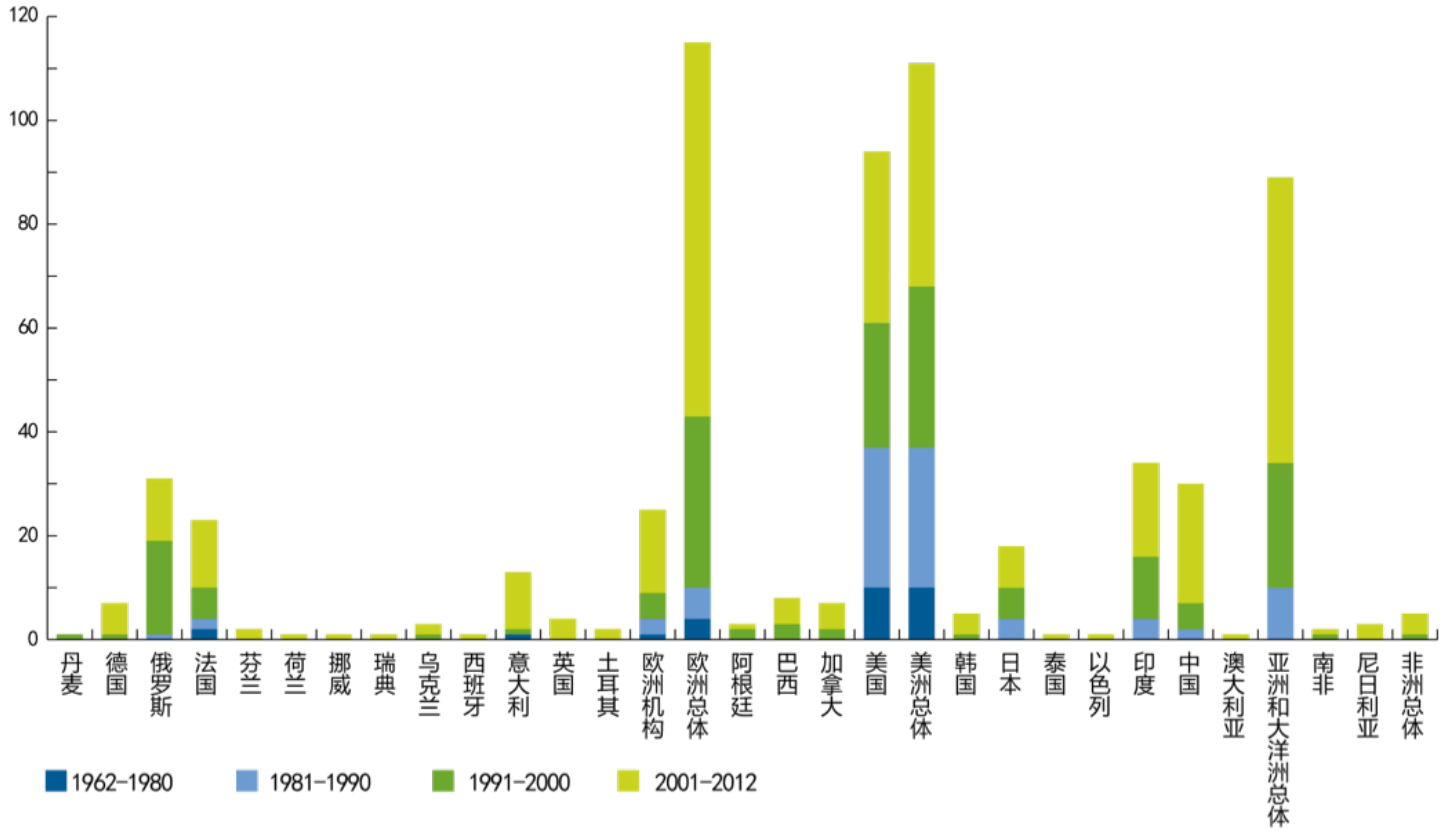
ToC

International Development of Earth Observation



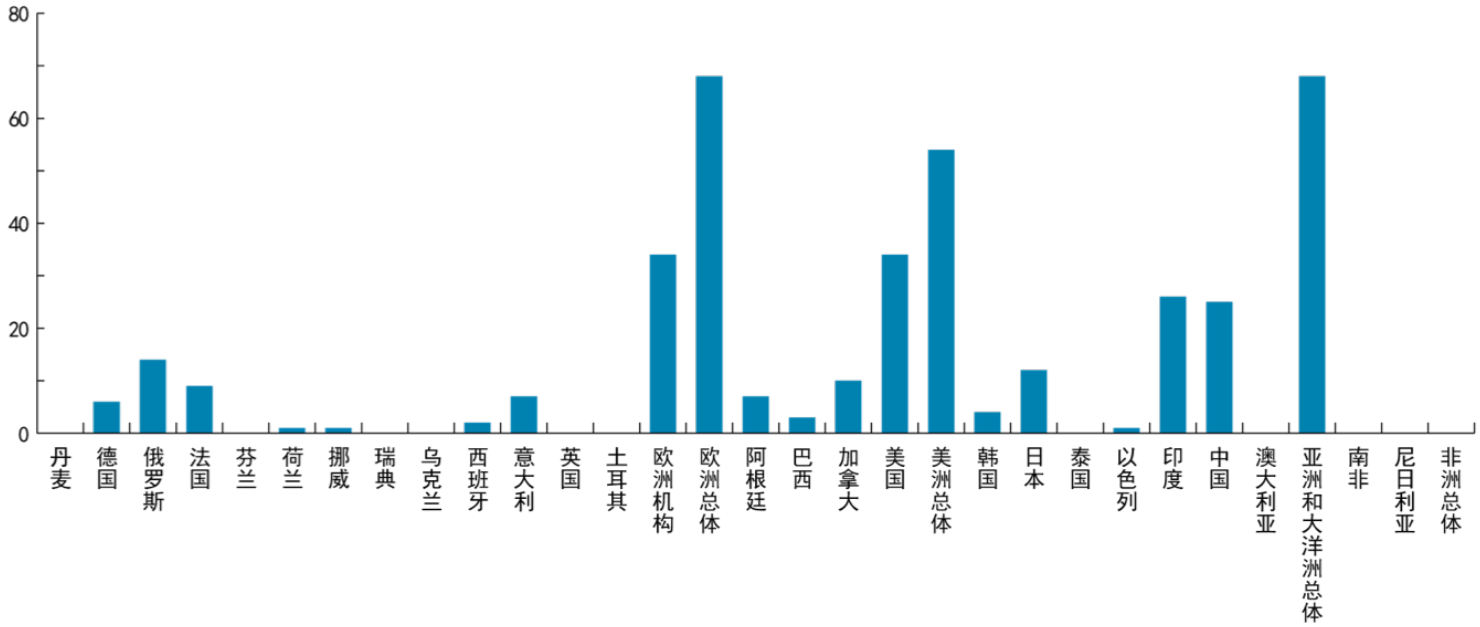
- Nimbus, 1964
- 514 EO satellites till Dec. 2011
- EO has played an important role for human being society

International Development of Earth Observation



- EO satellites in 1962-2012

International Development of Earth Observation



- Plan of EO satellites in 2013-2035

Earth Observation in China

- China Remote Sensing Satellite Ground Station, a member of the Landsat Ground Station Operations Working Group, boasts one of the world's highest capacities for receiving, processing, and distributing satellite data. With over 3.3 million scenes of satellite data accumulated on file since 1986, it is regarded as the largest Earth observation satellite data archive in China.
- Its three stations at Miyun, Kashi, and Sanya can receive data simultaneously from satellites covering the whole territory of China and 70% of Asia.
- It receives 12 satellites currently, will receive 50 satellite in 2025, and become the LARGEST ground station for civil use in the world.

Earth Observation in China

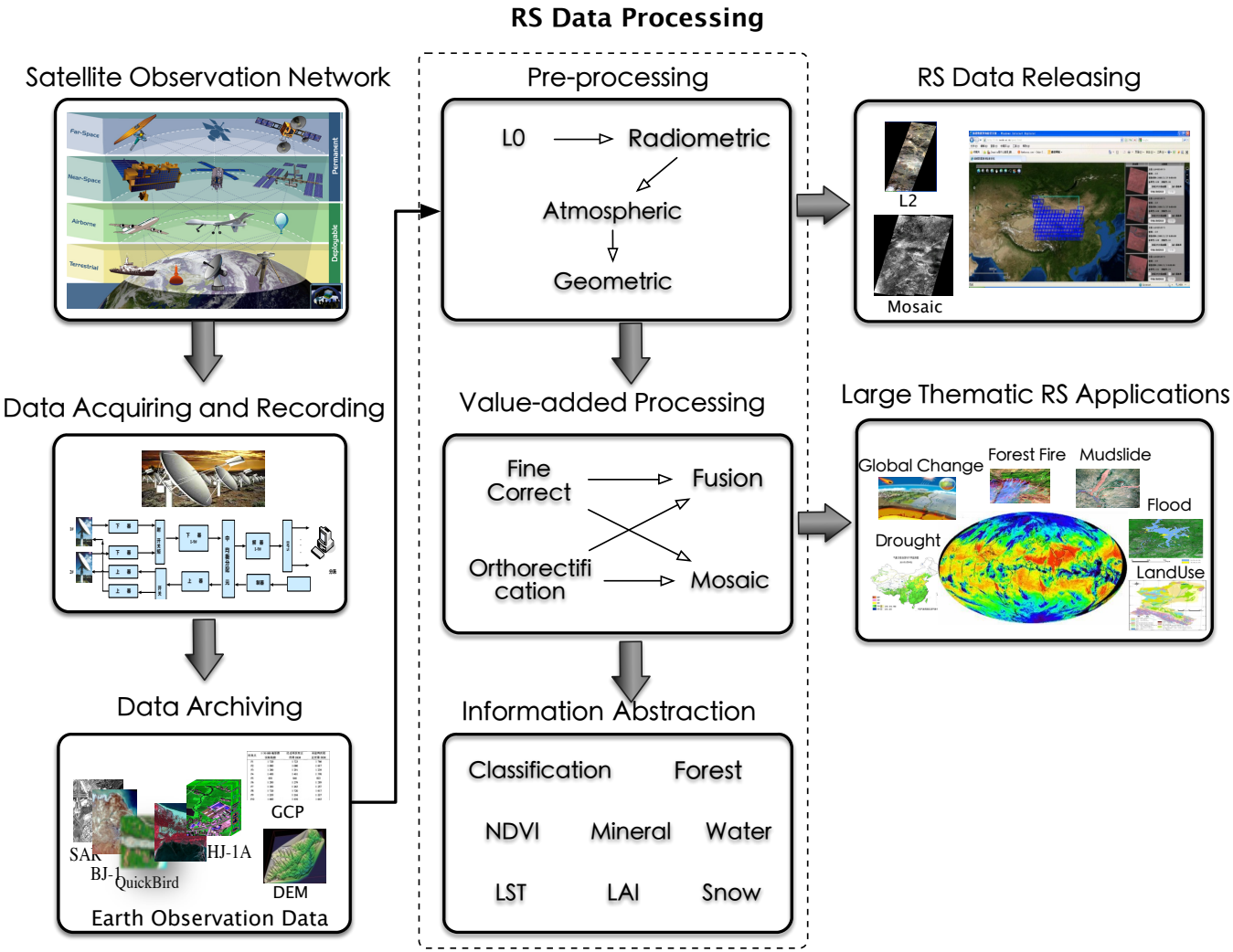
Earth Observation in China

表1 中国遥感卫星地面站所接收的国内外卫星数据一览表(截至2013年3月)

编号	卫星名称	所属国家或组织	开始接收时间	目前运行状况	
				卫星已失效	正常运行
1	LANDSAT-5	美国	1986	√	
2	ERS-1	欧空局	1993	√	
3	JERS-1	日本	1993	√	
4	ERS-2	欧空局	1995	√	
5	RADARSAT-1	加拿大	1997		√
6	SPOT-1	法国	1998	√	
7	SPOT-2	法国	1998	√	
8	CBERS-01	中国	1999	√	
9	SPOT-4	法国	1999	√	
10	LANDSAT-7	美国	2000	√	
11	SPOT-5	法国	2002		√
12	ENVISAT	欧空局	2003	√	
13	CBERS-02	中国	2003	√	
14	RESOURCESAT-1	印度	2005	√	
15	CBERS-02B	中国	2007	√	
16	RADARSAT-2	加拿大	2008		√
17	HJ-1A	中国	2008		√
18	HJ-1B	中国	2008		√
19	THEOS	泰国	2011		√
20	资源一号02C	中国	2011		√
21	资源三号	中国	2012		√
22	实践九号A星	中国	2012		√
23	实践九号B星	中国	2012		√
24	HJ-1C	中国	2012		√

ToC

EO Data Processing flow: an Overview



Data acquisition: data volumes and data rates

Satellites	Data Rates (MB/S)	Data Amount (GB/Day)	Data Amount (TB/Year)
ZY-02	113.98	115	40.99
ZY-03	304	334	119.05
HJ-1A	120	114	40.63
HJ-1B	60	57	20.32
HJ-1C	320	187.5	66.83
LandSat8	440.00	241.70	47.33
RadaSat2	105.00	57.68	11.29
RadaSat-1	105.00	57.68	11.29
SPOT-5	100.00	54.93	10.76
LANDSAT5	85.00	28.02	9.99
SPOT-4	50.00	10.99	3.92
RADARSAT-1	105.00	34.61	12.34
ENVISAT	100.00	32.96	11.75
IRS-P6	210.00	46.14	16.45

- Single RS data set: GB
- Daily receiving RS data set: TB
- National RS data archive: PB
- International RS data archive: EB

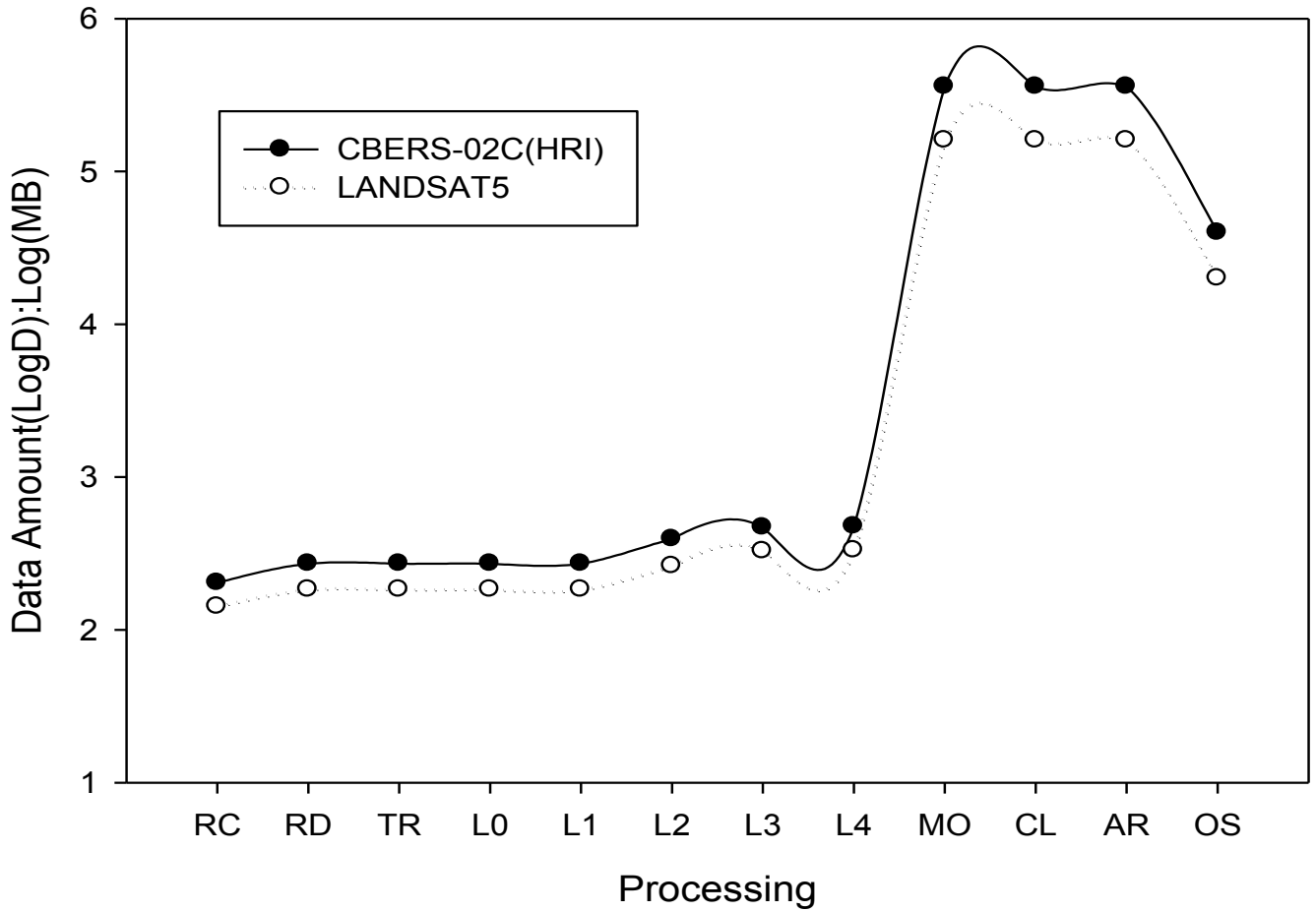
Data volumes of a single scene of L0, L1, and L2 Products

Satellites(Sensor)	L0(MB)	L1(MB)	L2(MB)
BJ-1(MS)	228.3	228.3	333.32
BJ-1(PAN)	98.9	98.9	150.33
SPOT-5(PAN)	572	572	45.96
SPOT-5(MS)	144	144	252.21
LANDSAT7(ETM)	337	337	532
LANDSAT8(UTM)	481	481	781

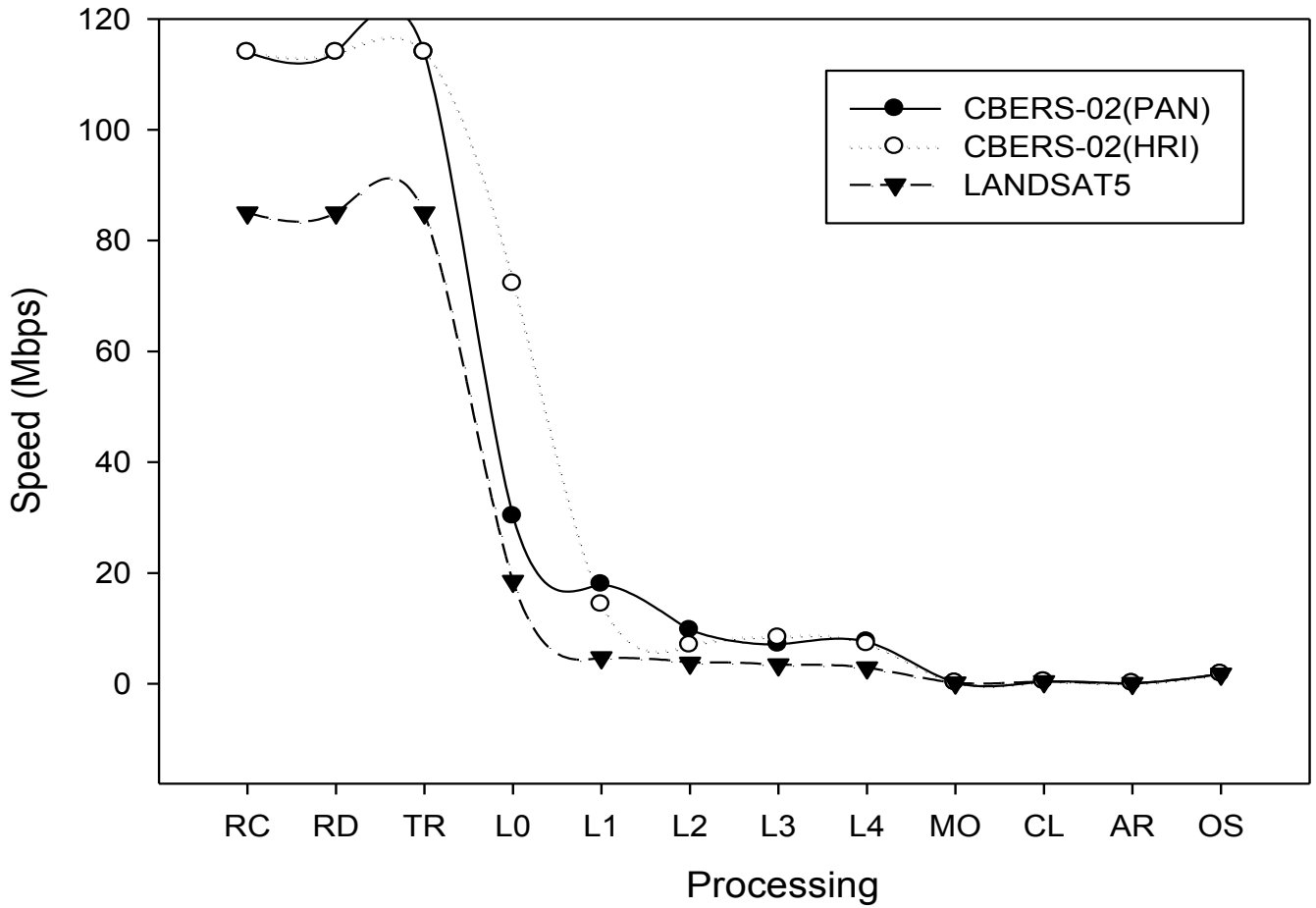
Data volume of value-added processing

Satellites (Sensor)	Fine 1 Scene(MB)	Ortho 1 Scene(MB)	Regional Mosaic (GB)	
			15 Scenes	512 Scenes
LANDSAT7	511.52	515.3	7.48	255.5
ZY-02C(PAN)	201.61	206.65	N/A	N/A
ZY-02C (HRI)	467.3	475.15	N/A	N/A

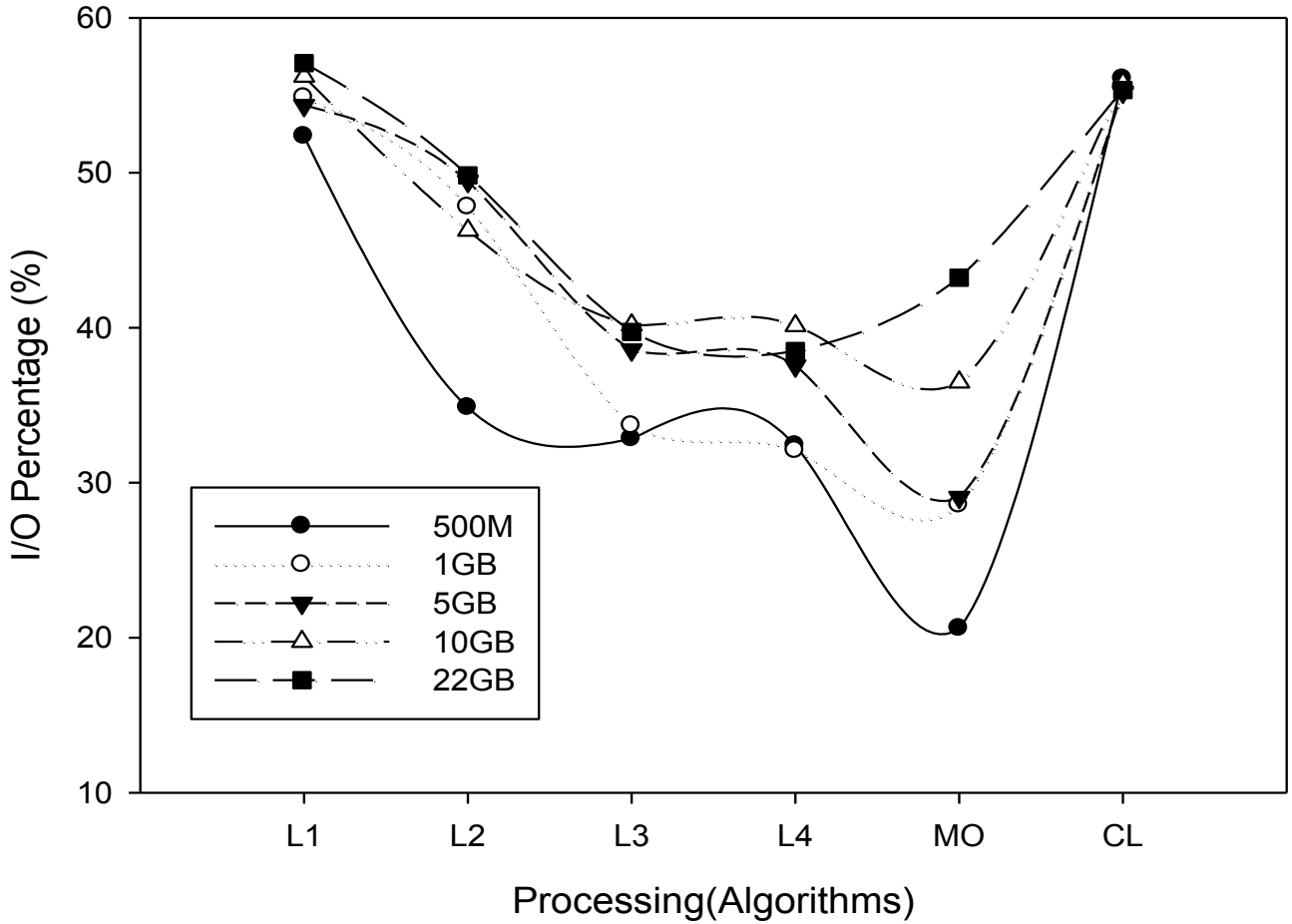
Data Volume Throughout the Entire Flow



Comparative analysis of the data throughput rate



Comparative Analysis of I/O Occupation

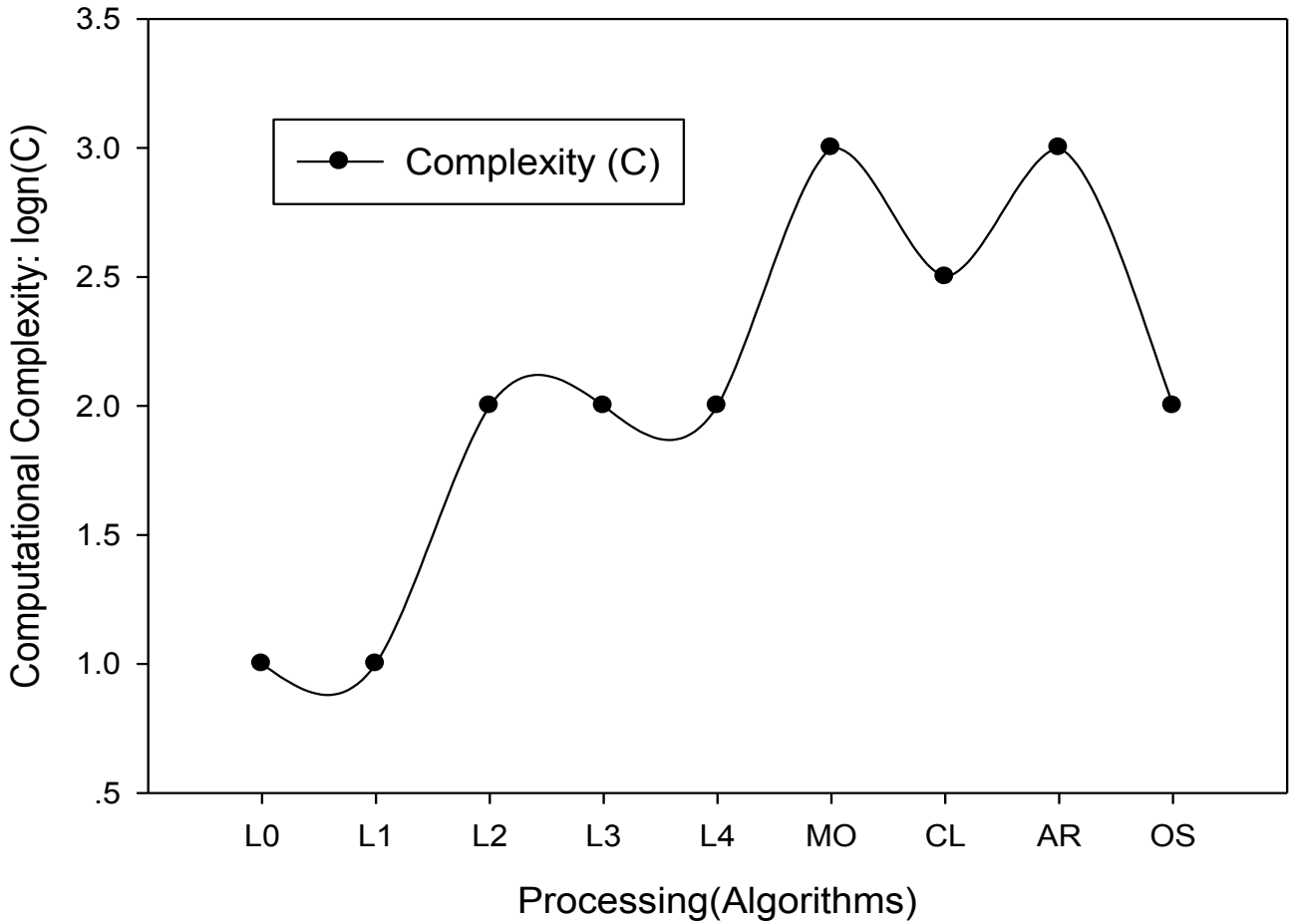


Yan Ma, Lizhe Wang. Towards building an empirical index for data-intensive remote sensing image processing applications. Future Generation Computer Systems.

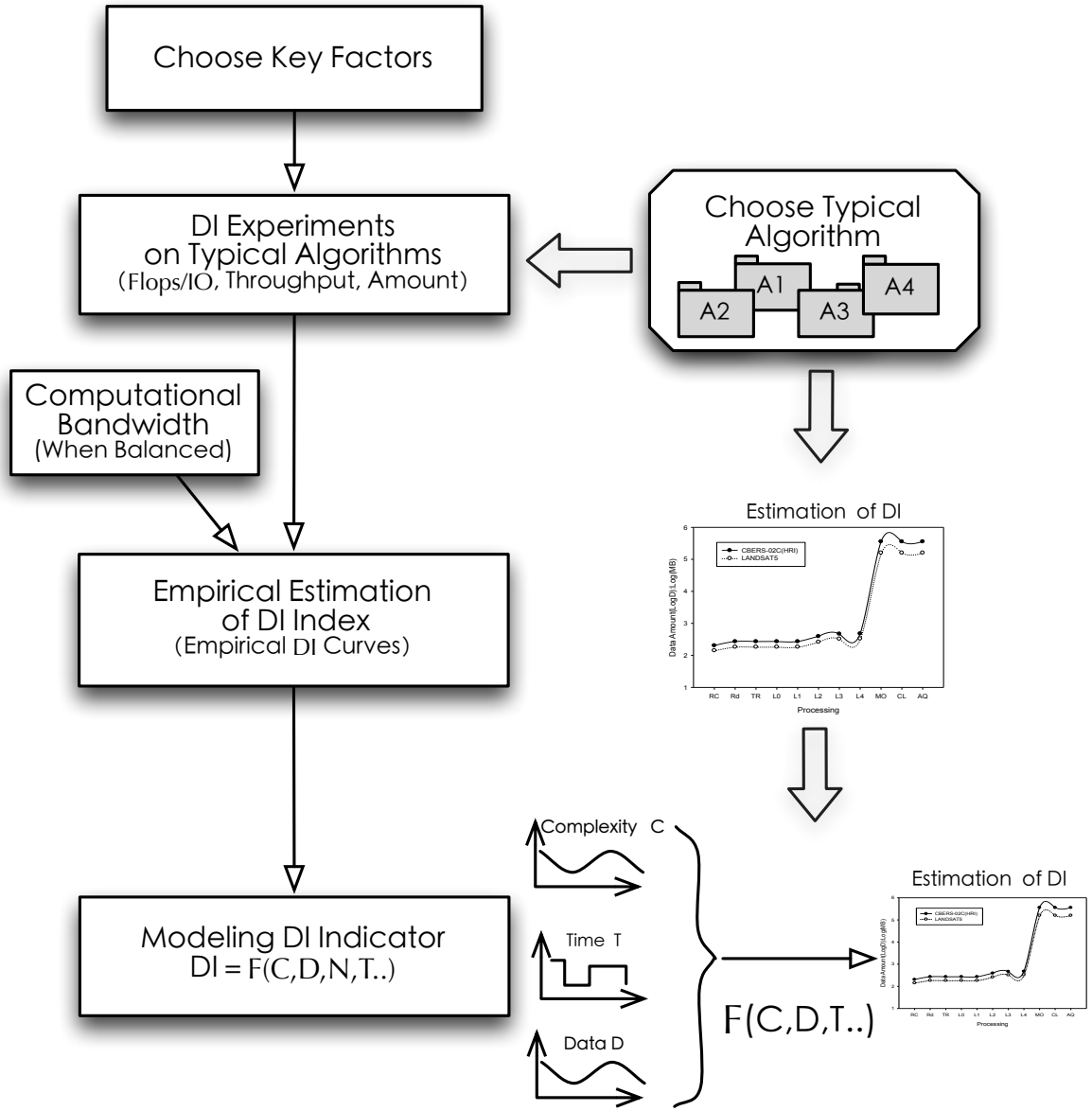
Computational Complexity of Algorithms

Stage	Algorithm	Complexity	Parallelism
Preprocessing	Radiometirc	O(n)	Excellent
	Geometirc	$O(n^2)$	Excellent
	Registration	$O(n^2 log(n))$	Excellent
Value-added Processing	K-T Trans	$O(p^2 bn^2)$	Good
	Convolution	$O(k^2 n^2)$	Good
	Mosaicking	$O(n^3)$	Normal
Information Extraction	K-mean	$O(rbmn^2)$	Normal
	Bayers	$O(bmn^2)$	good
	BP	$O(n^2 log(n))$	good

Computational Complexity of Algorithms



The DI_{RS} model

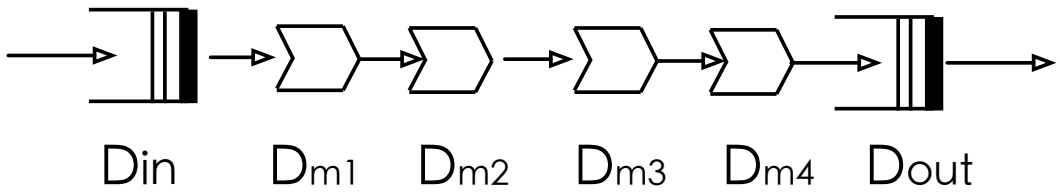


The DI_{RS} model

$$DI_{RS} = \begin{cases} 0 & \textbf{if} \quad \dfrac{10^{DC}}{60^{T}} < 1 \\ \log \dfrac{10^{DC}}{60^{T}} & \textbf{if} \quad \dfrac{10^{DC}}{60^{T}} > 1 \end{cases} \tag{1}$$

Representation of data volume 'D'

$$D = \max\{D_{in}, D_{m1}, D_{m2}, \ldots, D_{out}\} \tag{2}$$



Representation of time requirement 'T'

Table: Quantization of computational complexity 'C'

Computational Complexity	'C'
$O(n)$	1
$O(n^2)$	2
$O(n^2 log(n))$	2.5
$O(k^2 n^2)$	2.2
$O(n^3)$	3
$O(n^3) \sim O(n^4)$	4

Representation of computational complexity 'C'

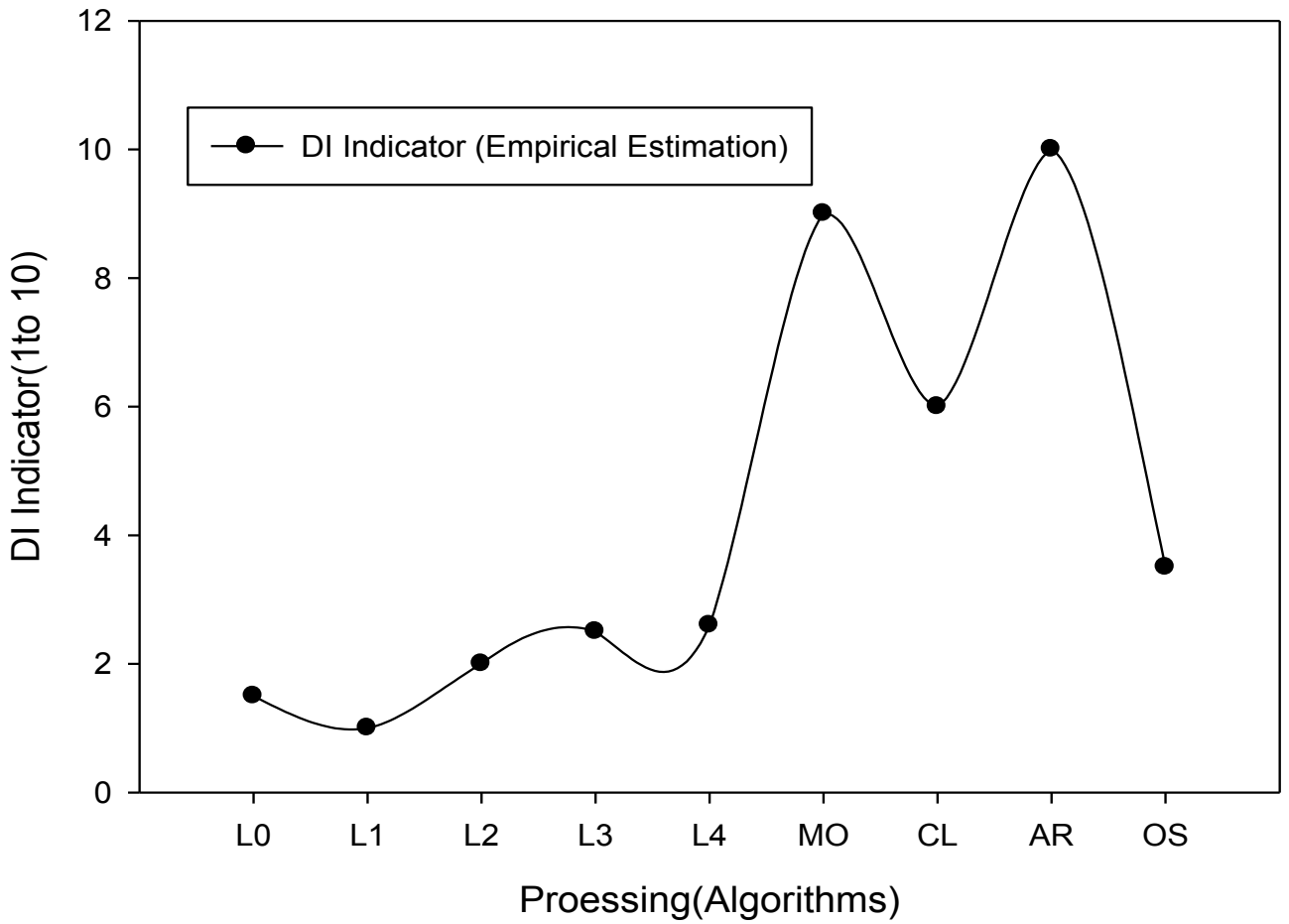
Table: Quantization of Time Requirement 'T'

Time Requirement	'T'
Second	1
Minute	2
Hour	3
Day	3.5
Week	4
>Month	5

Empirical Estimation of DI_{RS} Through the Entire RS Data Processing Flow

Algorithms	'C'	'D'	'T'	DI_{RS}
L1	1	3	2	0
L2	2	3	2	2.4
L3	2	3	2	2.4
L4	2	3	2	2.4
MO	5.5	5.5	3	11.2
CL	5.5	3	3	8.4
AR	5.5	3	3	11.2
OP	4.5	3	3	3.7

Empirical Estimation of the DI_{RS} Indicator



Some Findings for RS Big Data

- Big Data
- Compute-intensive and data-intensive
- Unbalanced Data Flow
- Complex Algorithm Flow

ToC

Philosophy of RS Big Data Computing

- Data processing models and algorithms
  - Approximate computation
  - Reduced Computation
  - Partial Computation
- System and Software
  - Platforms: Clusters, Data Centers, Clouds, High-speed networking
  - Software system: Parallel file systems, High Performance IO, Programming models, Memory models, Runtime System
- Paradigm of RS Data Product Service
  - Precise Prediction, On-Demand Computing, Active Service
  - Standalization, Serialisation and Automation of RS Data production

Philosophy of RS Big Data Computing

- Data processing models and algorithms
  - Approximate computation
  - Reduced Computation
  - Partial Computation
- System and Software
  - Platforms: Clusters, Data Centers, Clouds, High-speed networking
  - Software system: Parallel file systems, High Performance IO, Programming models, Memory models, Runtime Systems
- Paradigm of RS Data Product Service
  - Precise Prediction, On-Demand Computing, Active Service
  - Standalization, Serialisation and Automation of RS Data production

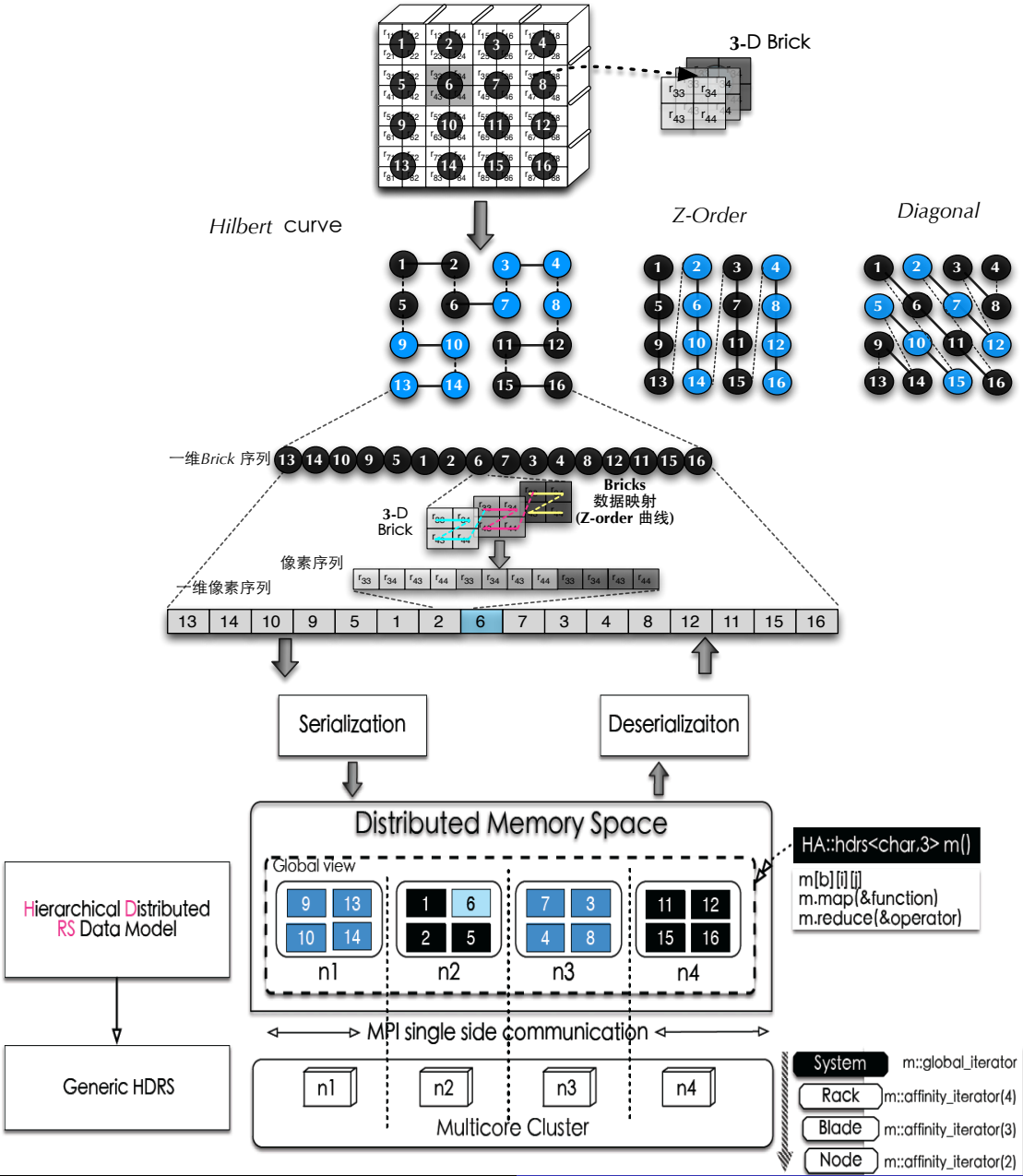
High Performance Processing for EO Big Data

- Where:
  - EO Big Data and its Applications
- What:
  - Quantitative analysis of EO Big Data and its processing algorithms
  - Structed, semi-structed and unstructured EO Big Data
  - High performance processing algorithms and software models

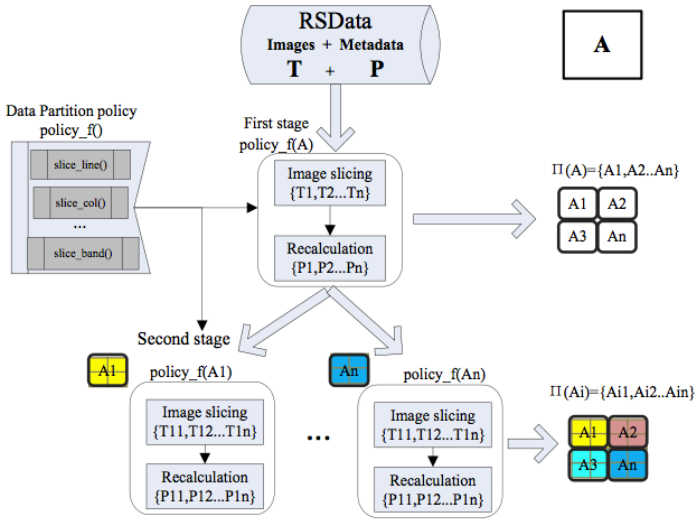
- Systems and Platforms
  - Clusters
  - Satellite data centres
  - Clouds, and Multiple datacenters
- Data Model
  - Memory model: GDDM
  - Storage model: HPGFS
  - IO model: ADIOS, HA
- Processing Model
  - Distributed Memory Processing Model(MPI)
  - Workflow Model
  - Batch Processing Model
  - Streaming data
- Production System
  - Parallel RS Image Processing System (PIPS, PIPS+)
  - RS Data Production System across Multiple Satellite Datacenters

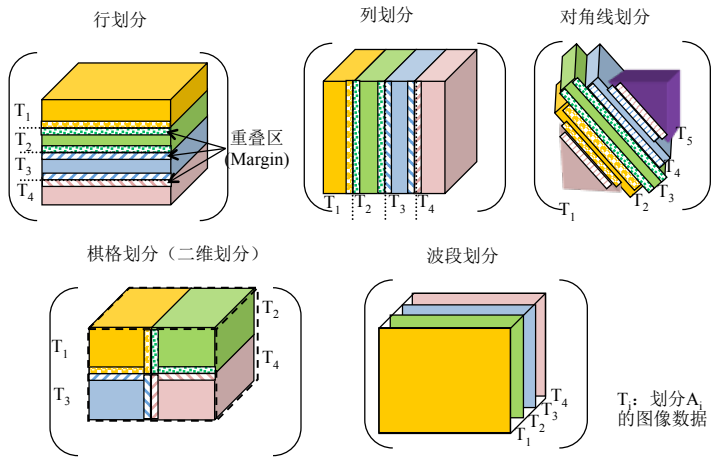
Contents

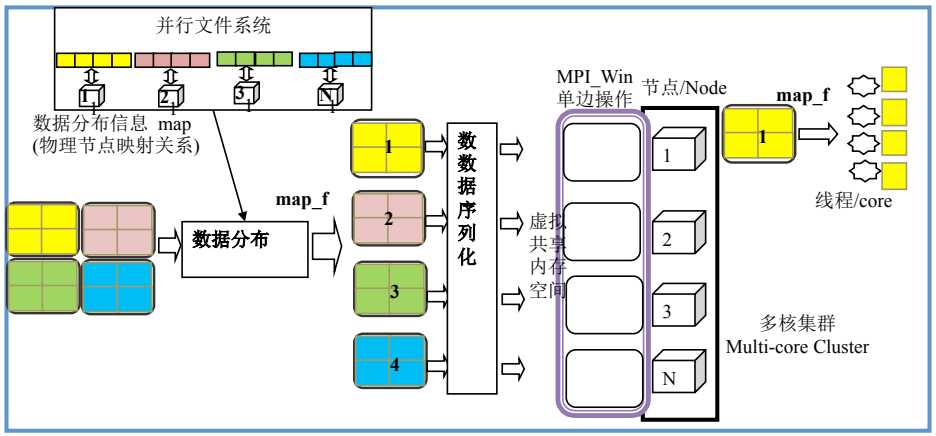
A System View

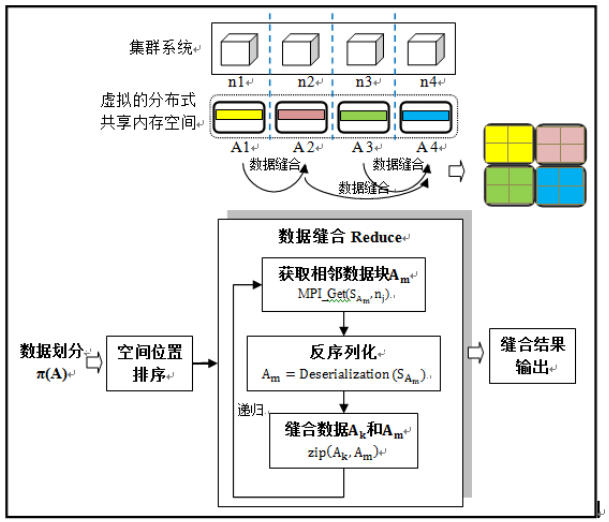


Implementation



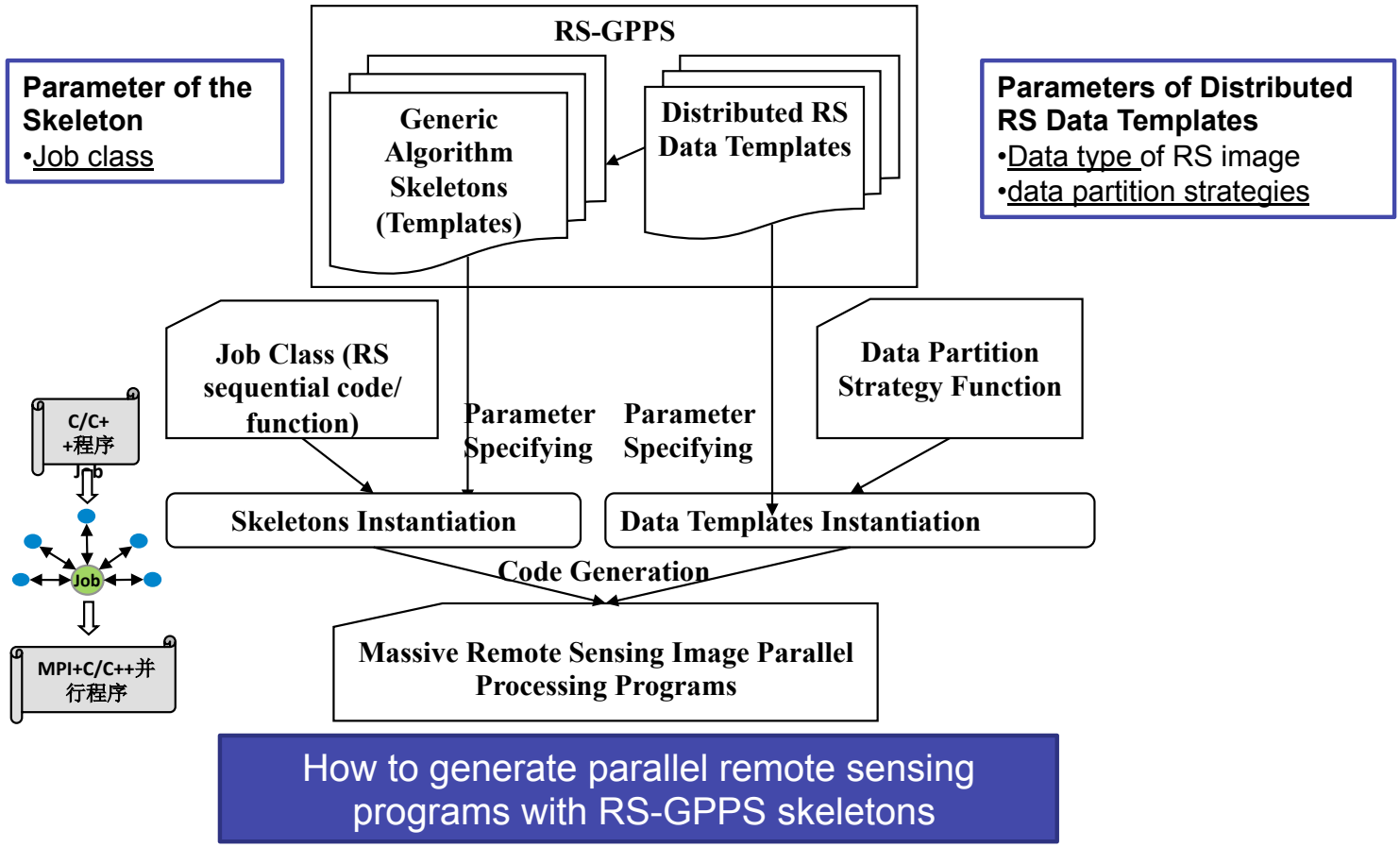






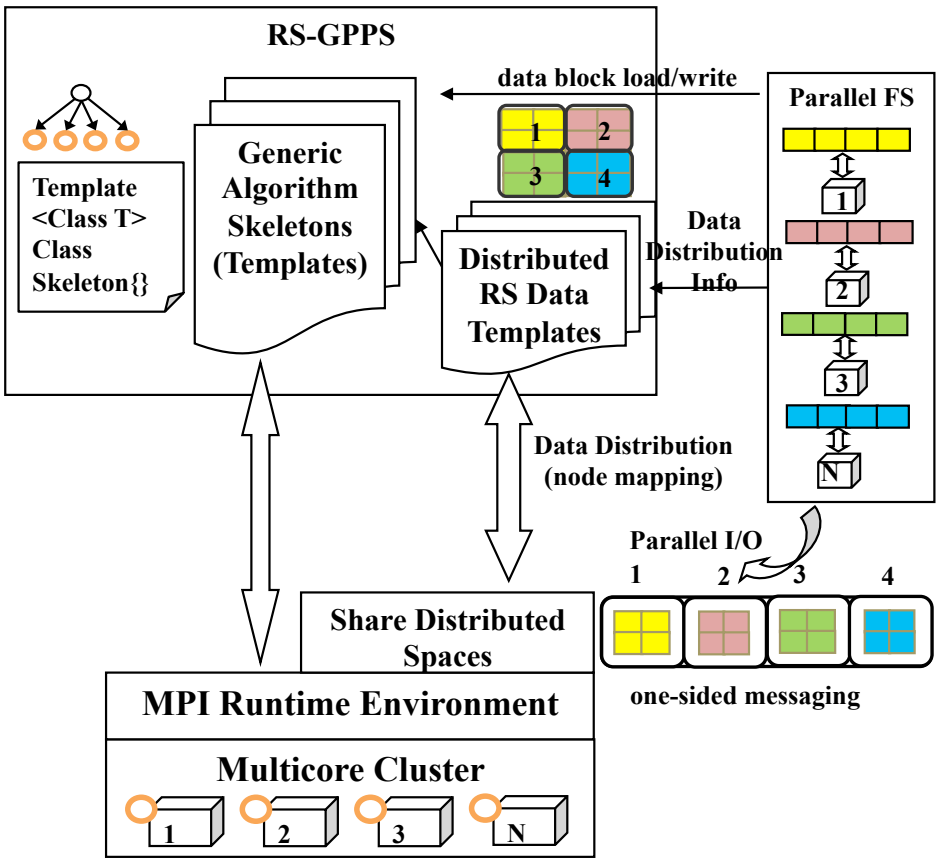
Contents

Generic Parallel Processing Model for RS Big Data



- Lizhe Wang, Yan Ma, etc. Yan Ma, Lizhe Wang, et. al. Generic Parallel Programming for Massive Remote Sensing Data Processing. CLUSTER 2012: 420-428

Generic Parallel Processing Model for RS Big Data



- **Implement Distributed RS Data**

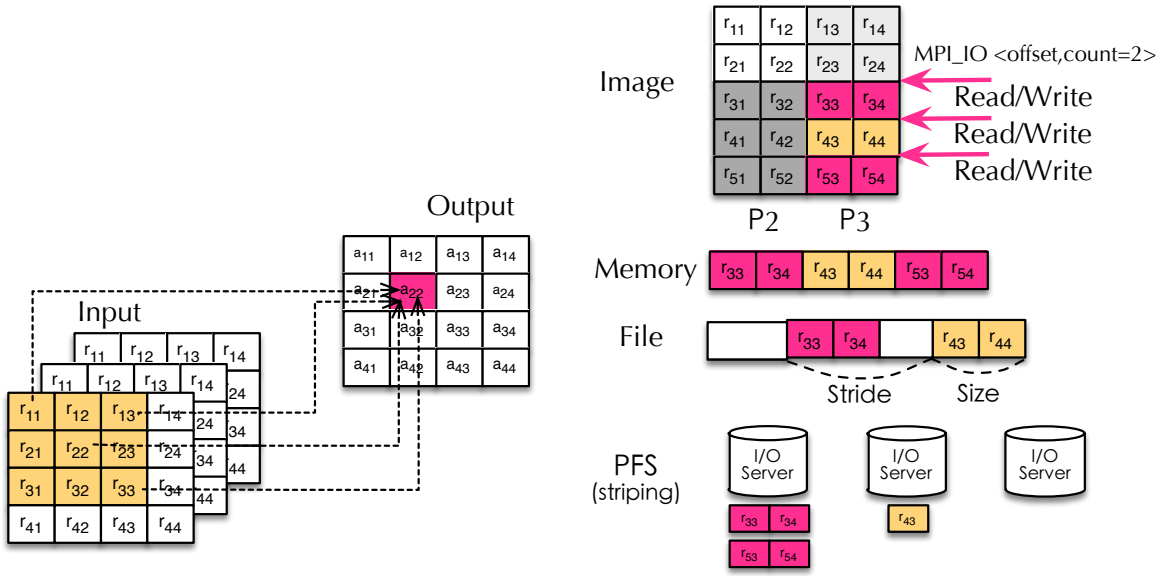
1)**Slice** RS data logically into **overlapped** blocks;
2) **Distributed** blocks across nodes;
3) **Converged** blocks as a **Global** RS data via **one-sided messaging** of MPI

- **Implement skeleton**

(Perform Computations on Distributed RS Data)
1) Divide the Task into subtasks;
2) **Load** the **Data Blocks** concurrently through parallel I/O;
3) **Execute Sequential Codes** in parallel

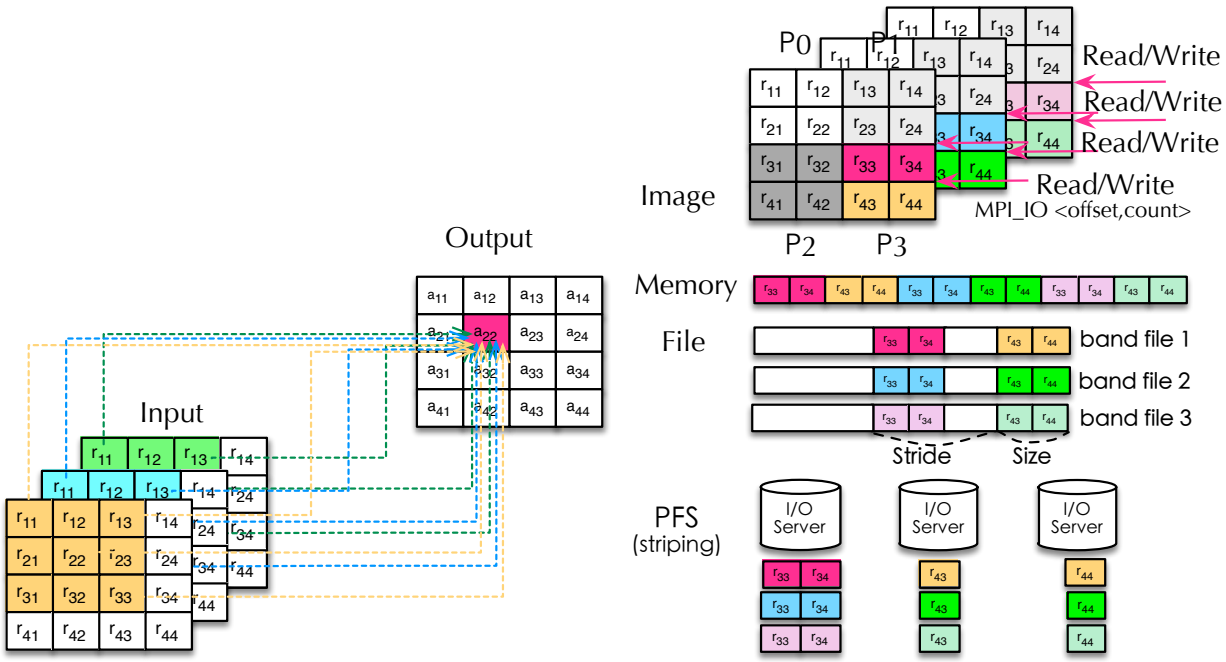
Contents

RS Data Access Pattern



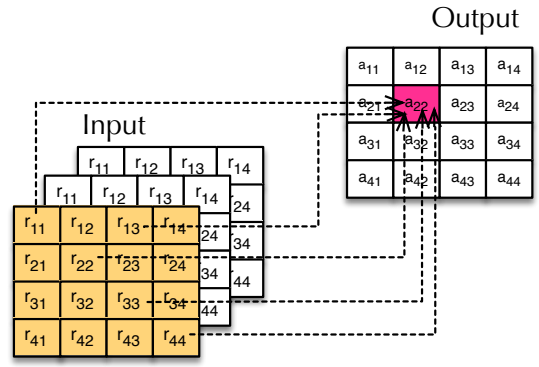
(a) Neighbor-Based Processing(Regional dependent) **(b) Rectangular-Block Access Pattern**

RS Data Access Pattern

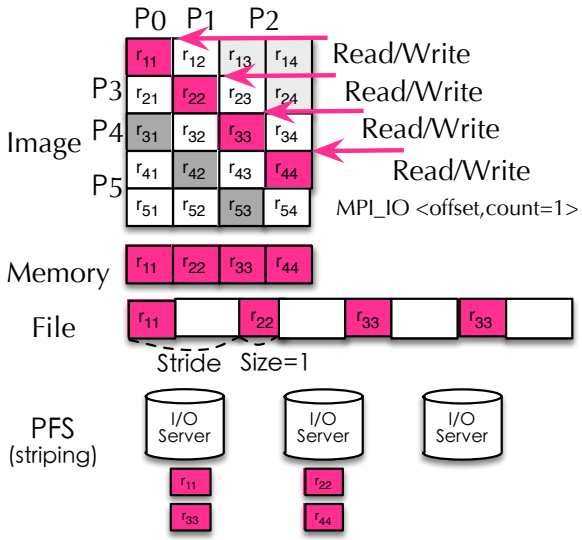


(a) Band-Related Processing(Band dependent) **(b) Cross-File Access Pattern**

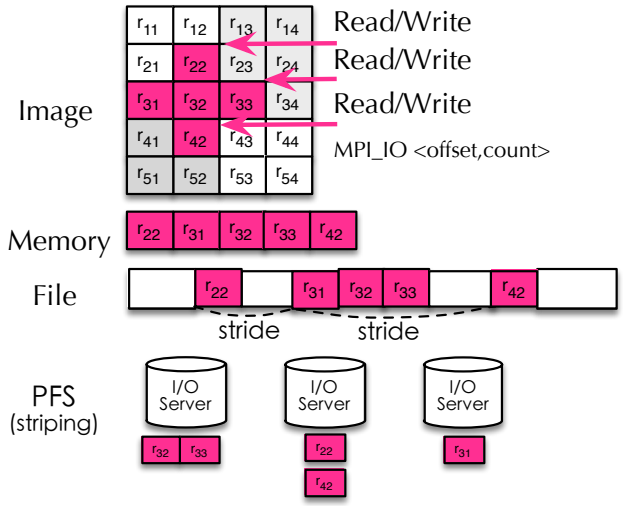
RS Data Access Pattern



(a) Irregular Processing(Global or Irregular Dependent)

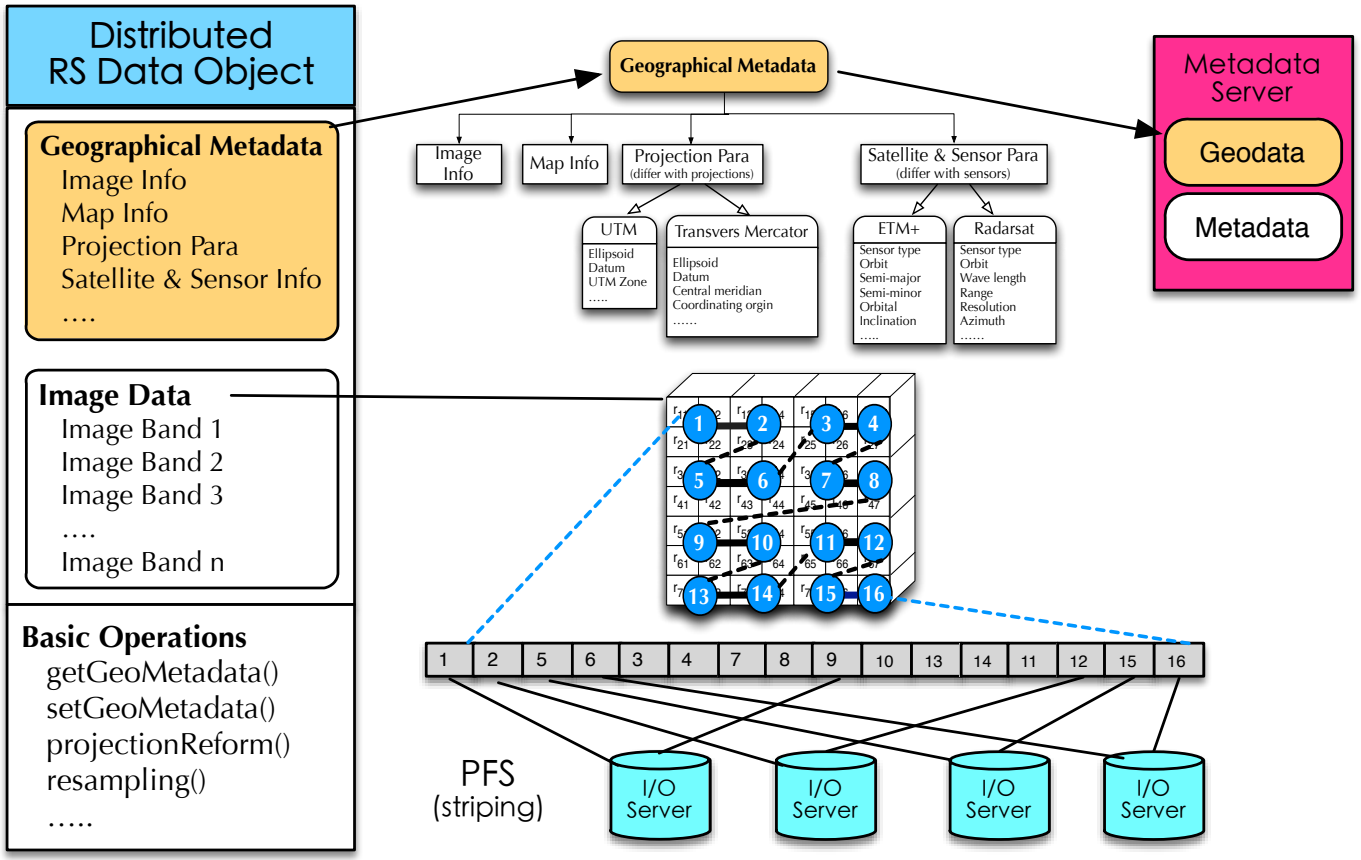


(b) Diagnal Access Pattern

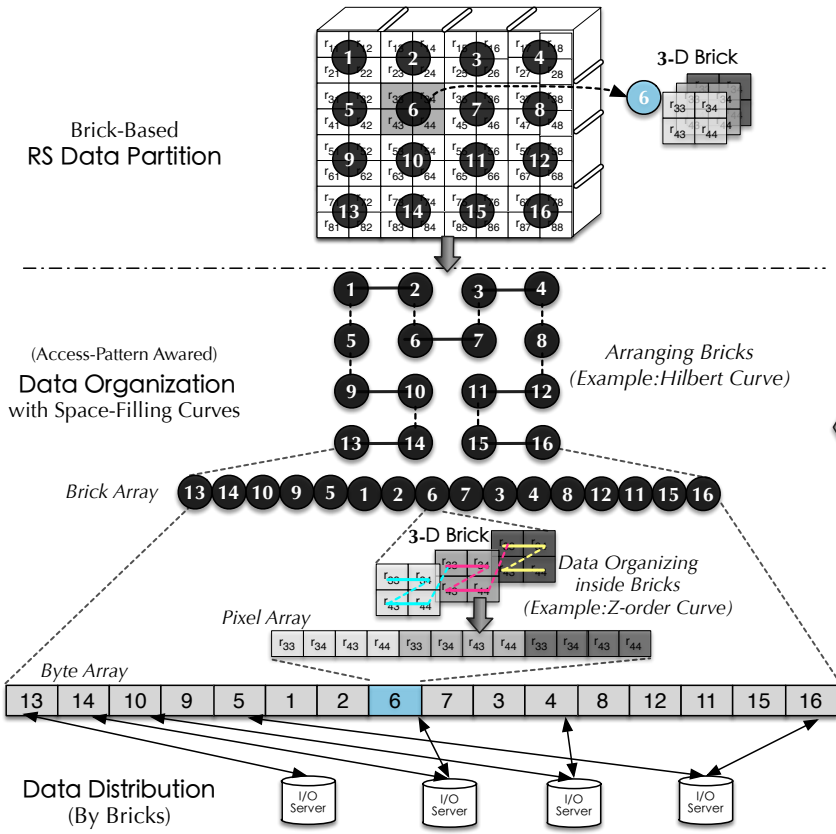


(c) Polygon Access Pattern

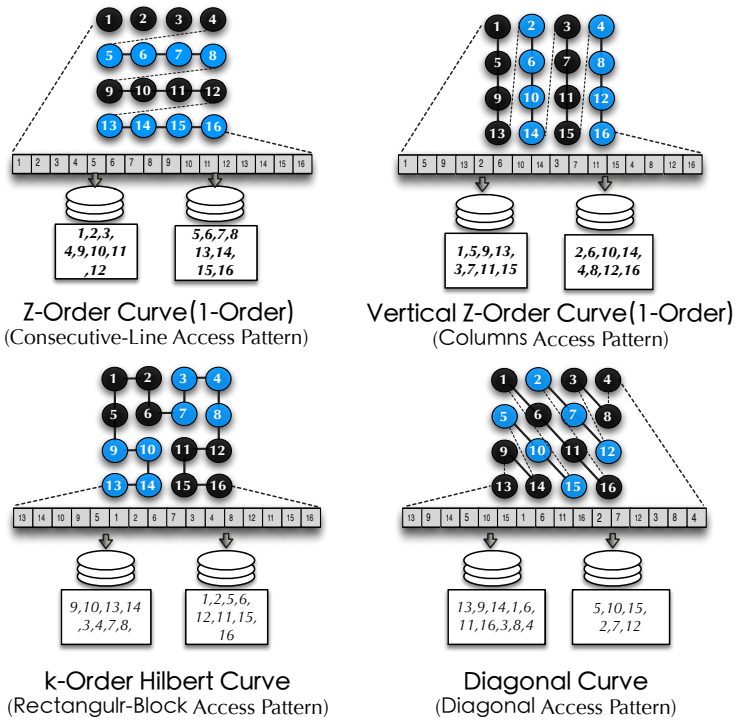
Optimized Data Layout in HPGFS



Optimized Data Layout in HPGFS



Building Data Layout with Application Aware Policies

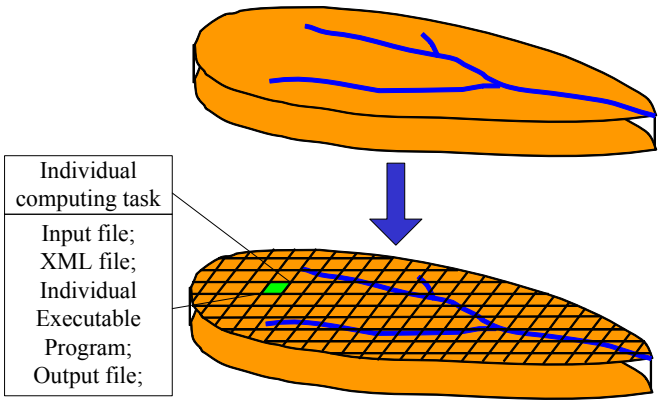


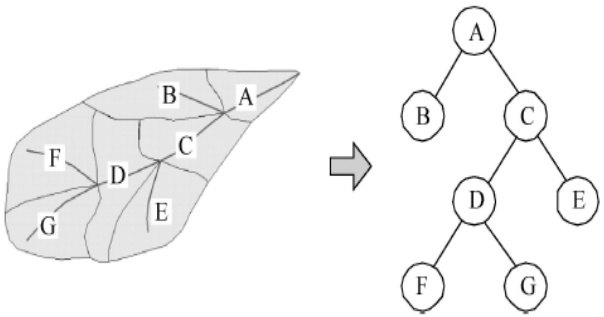
Different Space-Filling Curves for Different Access Patterns

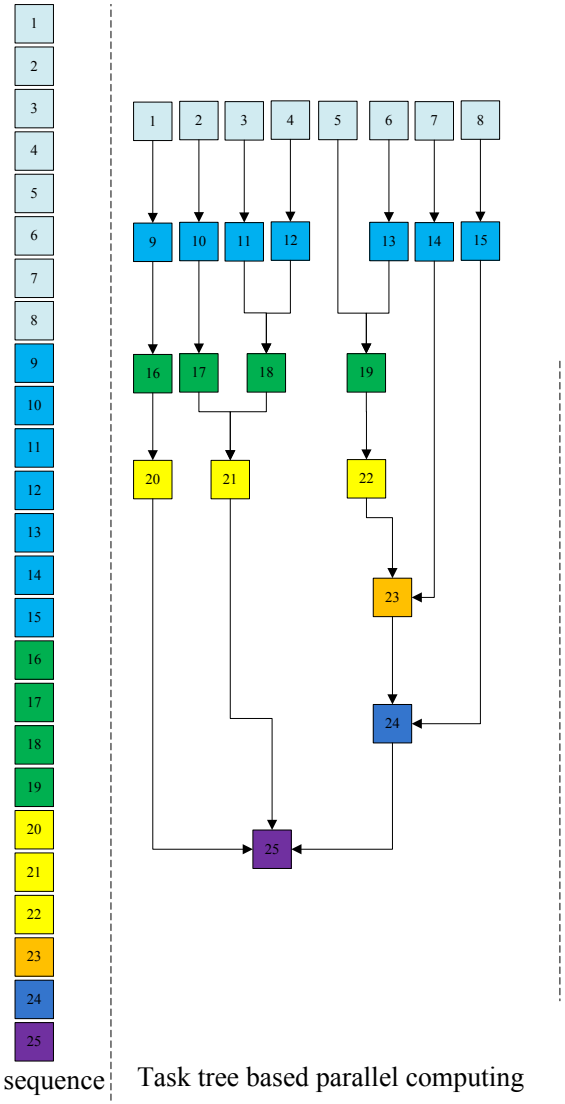
- Lizhe Wang, Yan Ma, etc. A Parallel File System with Application-aware Data Layout Policies in Digital Earth", IEEE Transactions on Parallel & Distributed Systems, doi:10.1109/TPDS.2014.2322362

Contents

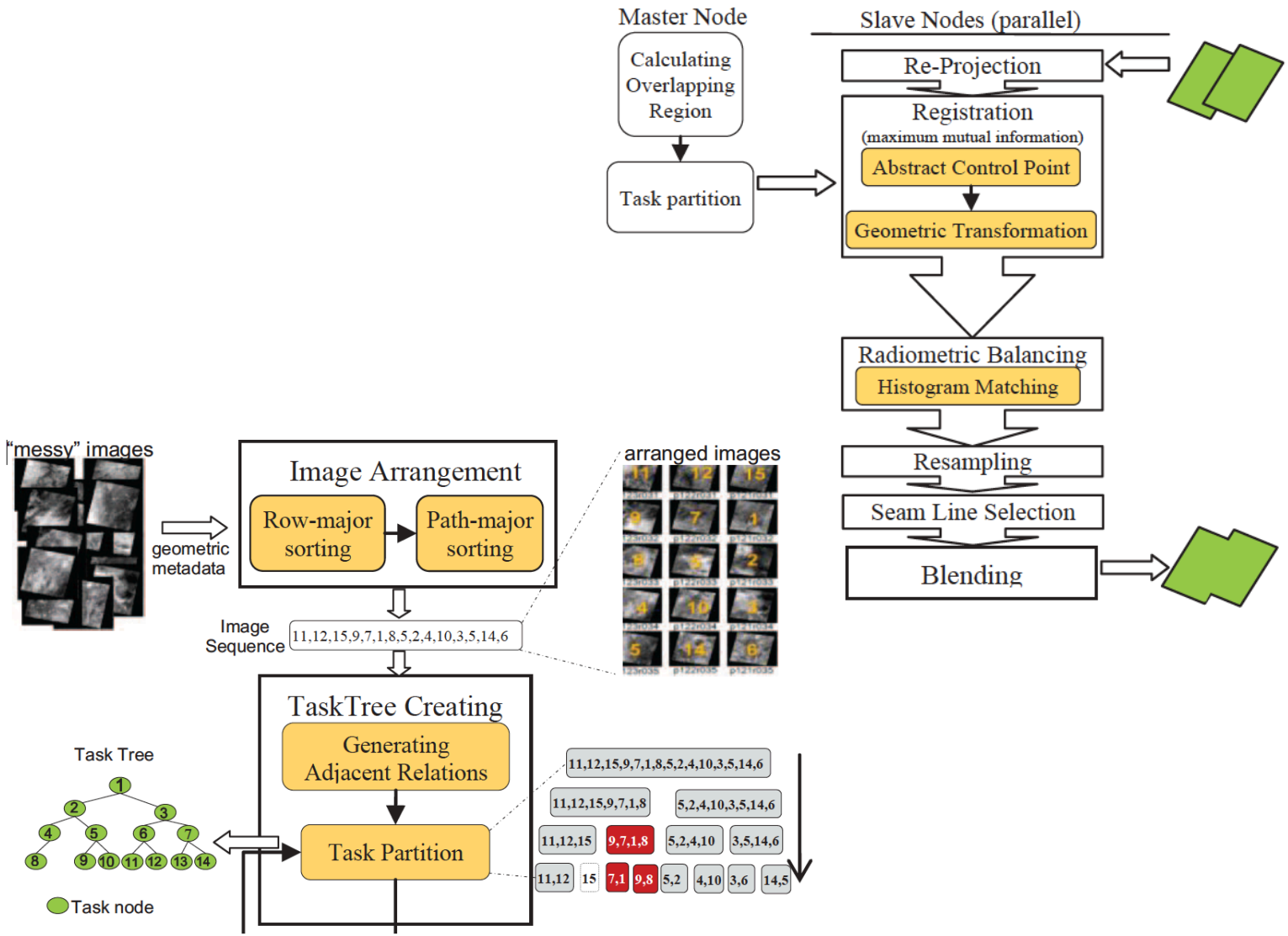
Large-scale RS images Parallel Processing



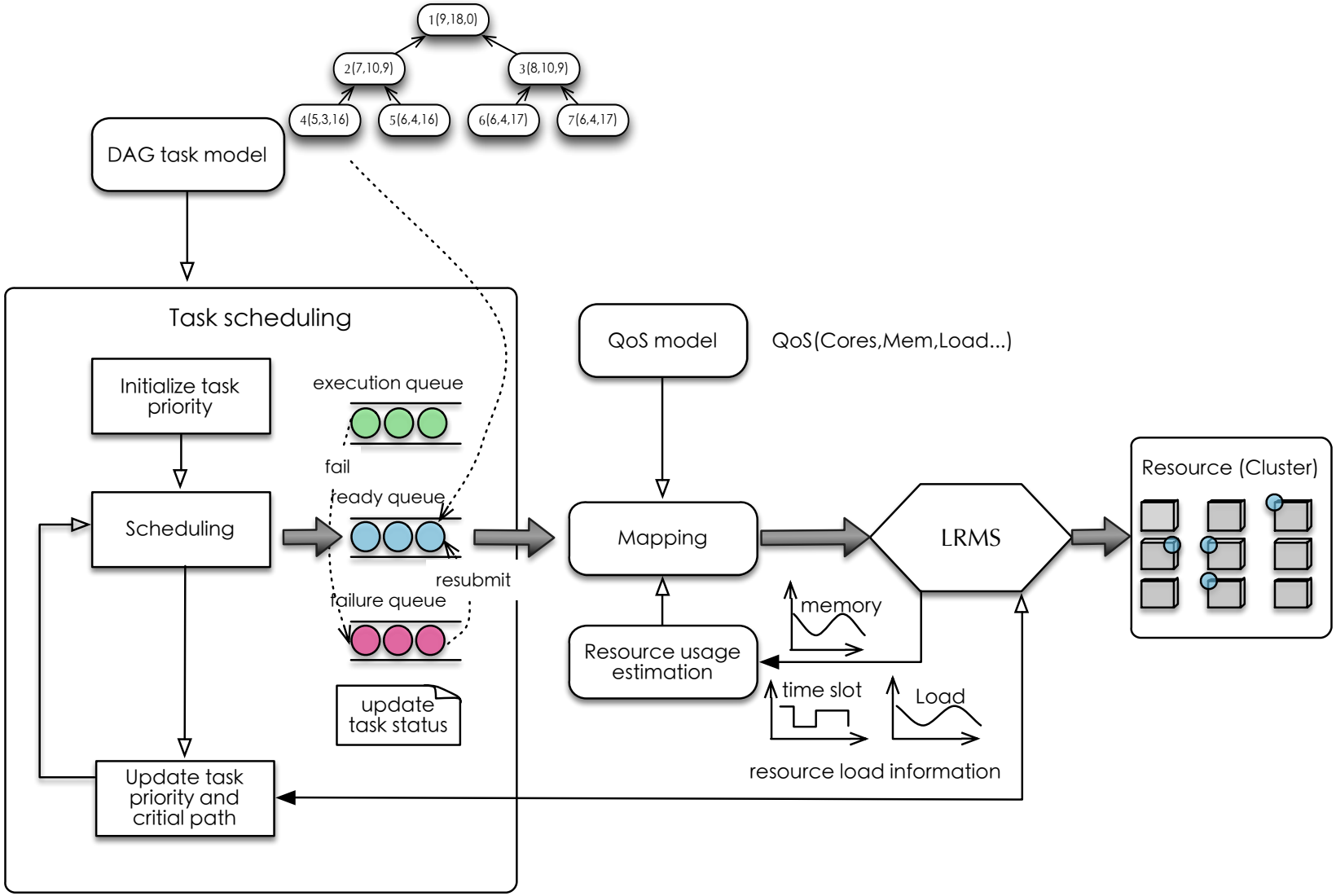




Large-scale RS images Parallel Processing



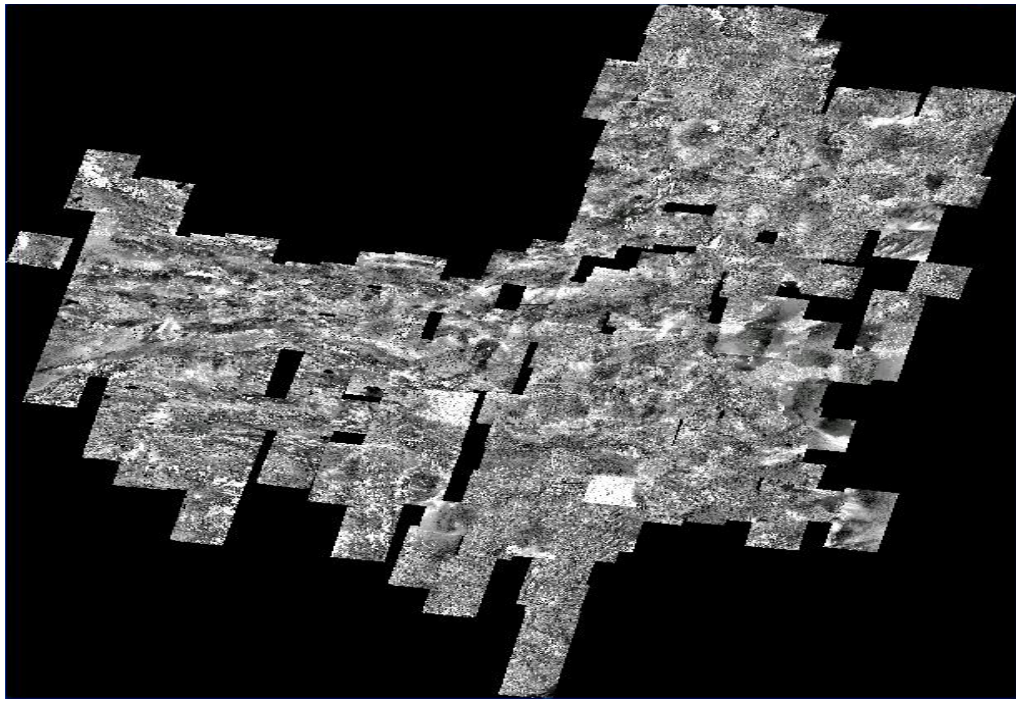
DAG-based scheduling model



- Yan Ma, Lizhe Wang, etc. Task tree based large-scale mosaicking for massive remote sensed imageries with

Large scale parallel RS Image Mosaicing

- Data: More than Half of China. (20° N–47° N and 84° E–180° E) 352 Scenes of ETM+, 15m resolution, PAN
- Performance: On a 10-node cluster, it takes 5 hours. typically it is several-day work with a commercial software



ToC

Multi-datacenter Clouds for RS Data Processing

- Multiple Datacenter Collaborative Process System (MCCPS)
  - Join 6 RS data centers of China;
  - Process 12+ multi-source RS data;
  - The amount of data is over 1 PB

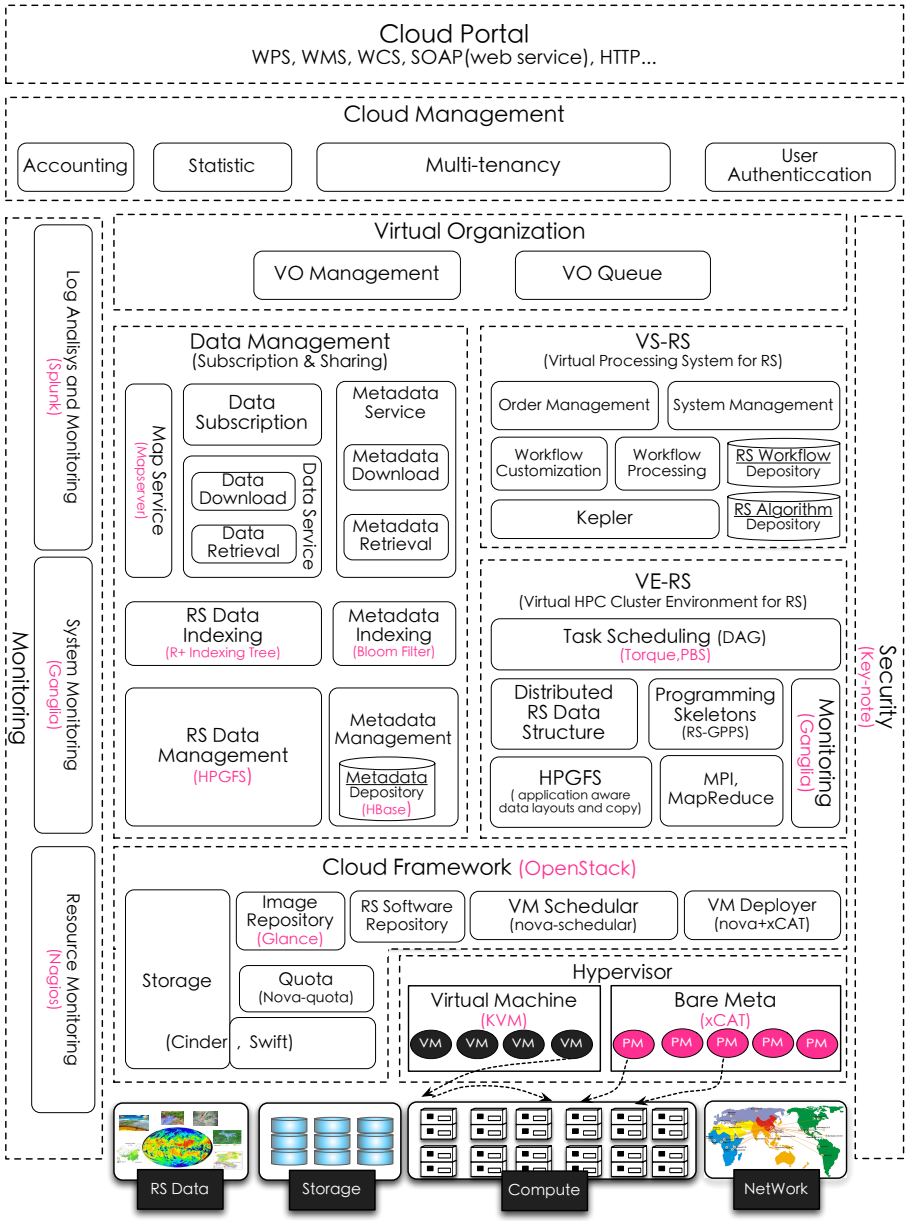
	Data Center	Satellite
1.	CRESDA	CBERS,HJ,ZY
2.	NSOAS	HY
3.	NSMC	FY3A, FY3B, FY2E
4.	CNIC	LandSat, MODIS
5.	21AT	BJ-1
6.	RADI	ENVISAT-1, IRS-P6
Data Volume		>1PB

Multi-datacenter Clouds for RS Data Processing

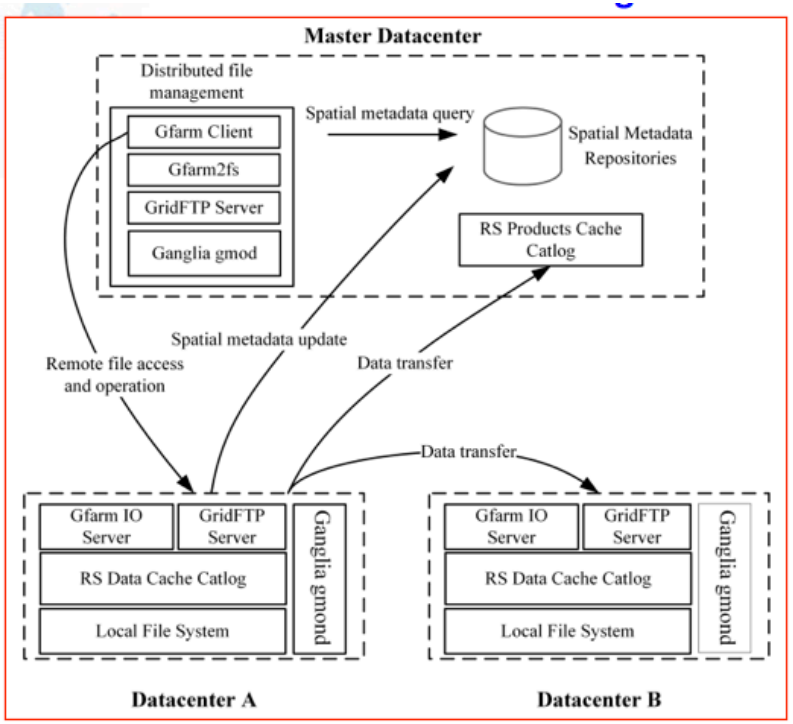
- Products provide
  - 40+ types of RS inversion products: vegetation structure and growth state, radiation budget, water and heat fluxes, ice-snow variation, mineral exploration
  - 20+ types of thematic RS products: agriculture, forestry, geology, water , sea ice, environment
  - large scales area: global, China, South America
  - long time series: all year round
- Service provide
  - spatial metadata management for multi-level RS data;
  - data-dependent knowledge base;
  - replicas management for distributed RS data;
  - automated data production;
  - production task scheduling;
  - workflow fault-tolerant;
  - distributed resource monitoring

- Lizhe Wang, etc. pipsCloud: High Performance Cloud Computing for Remote Sensing Big Data Management and Processing. Submitted to FGCS.

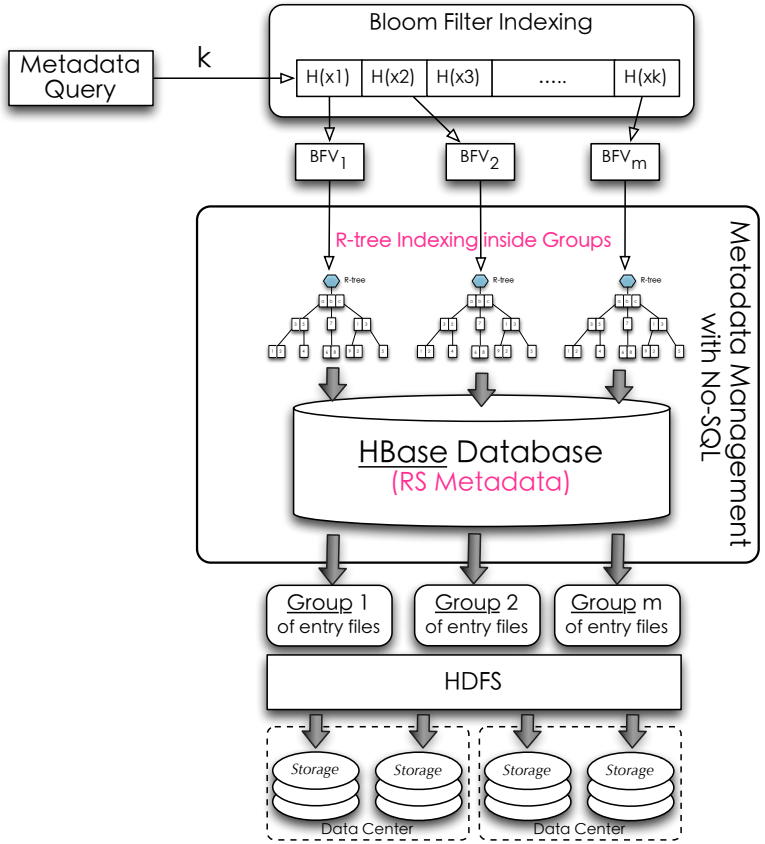
Software System Architecture



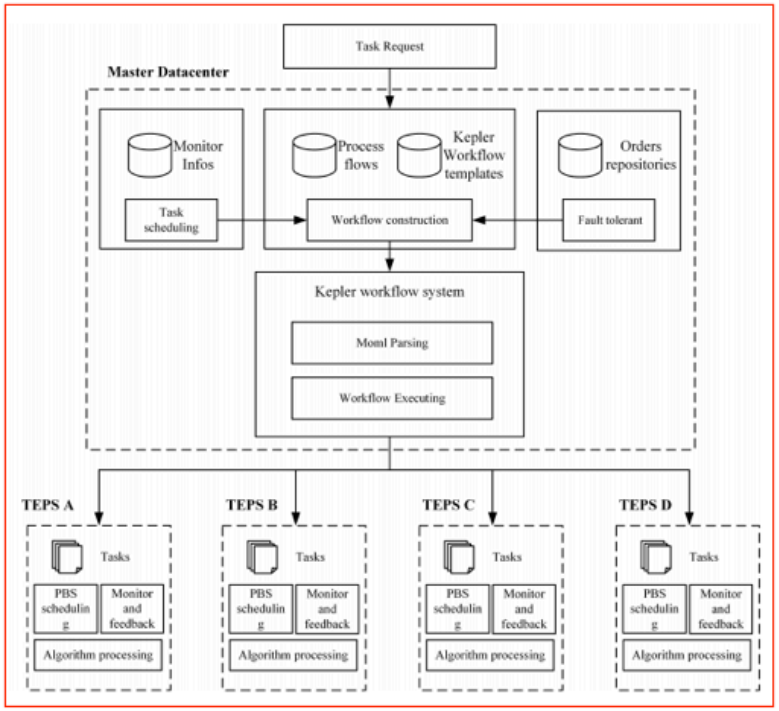
RS file management



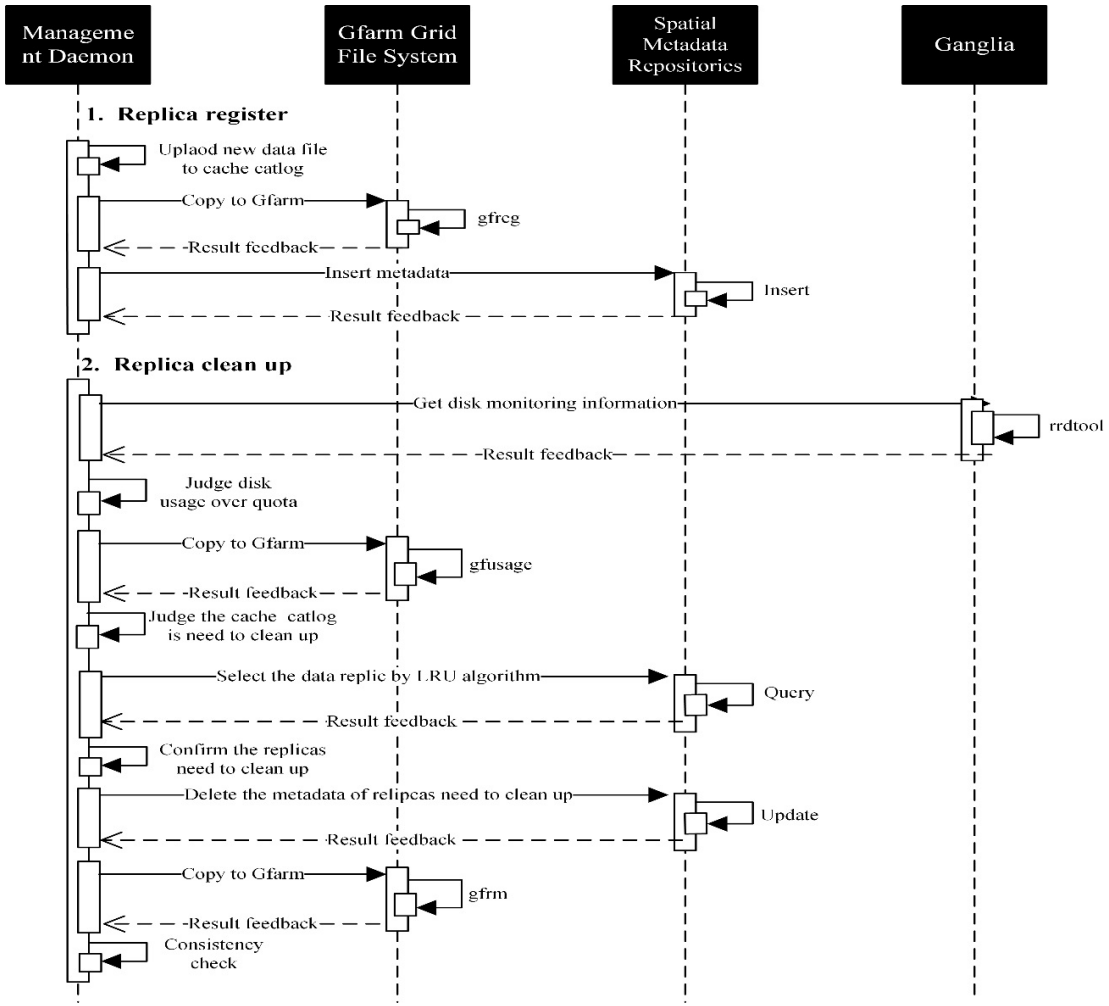
RS Metadata management



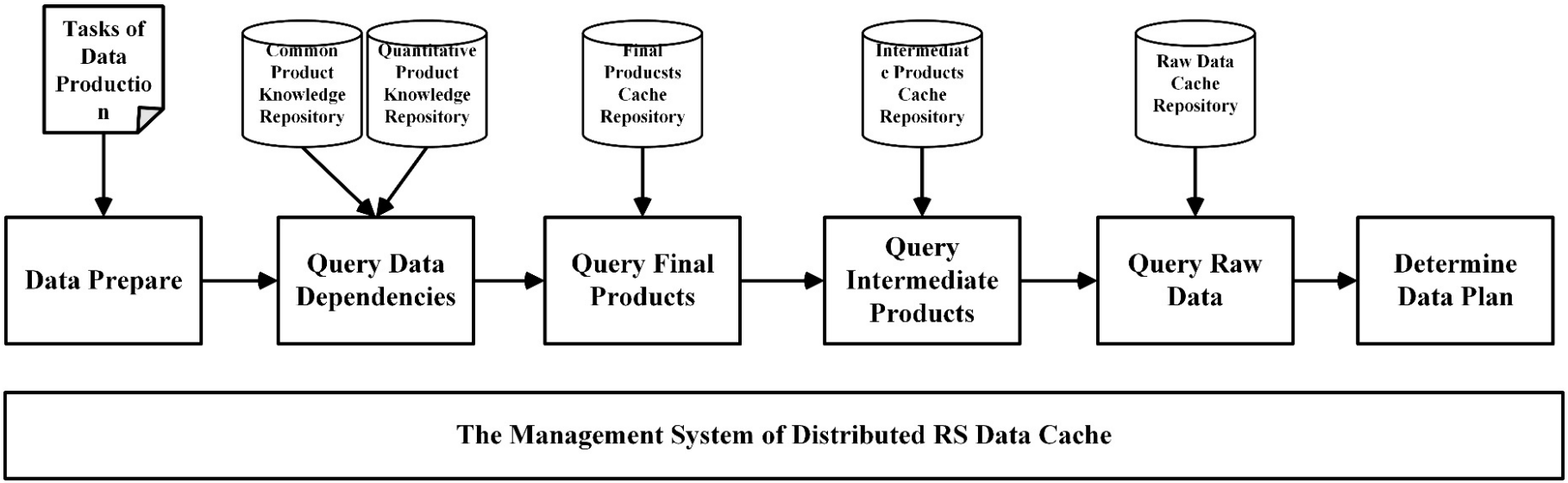
RS Workflow Management



RS Replica and Cache Management



RS Replica and Cache Management



ToC

Concluding Remark for RS Big Data

- Findings
  - Big Data
  - Compute-intensive and data-intensive
  - Unbalanced Data Flow
  - Complex Algorithm Flow
- Recommendation
  - Specially optimized HPC software systems for data transfer, IO, storage, processing and management

Thank you for your time !