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Secure Multimedia Processing over Cloud

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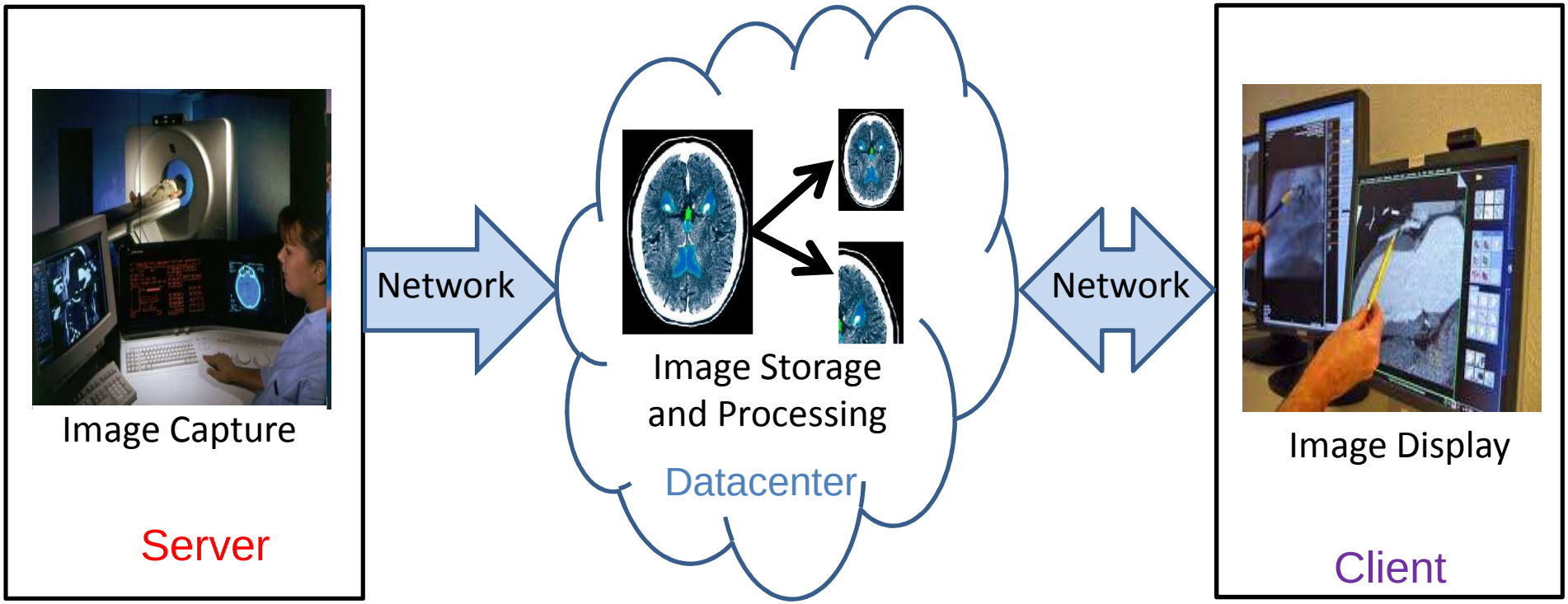
Cloud-based Multimedia Computing

- Very popular these days
- Companies Offering 2D Imaging
  - AT&T, Dell, Intel etc.
- Companies Offering 3D Imaging
  - Microsoft, KDDI, Sinha Systems etc.

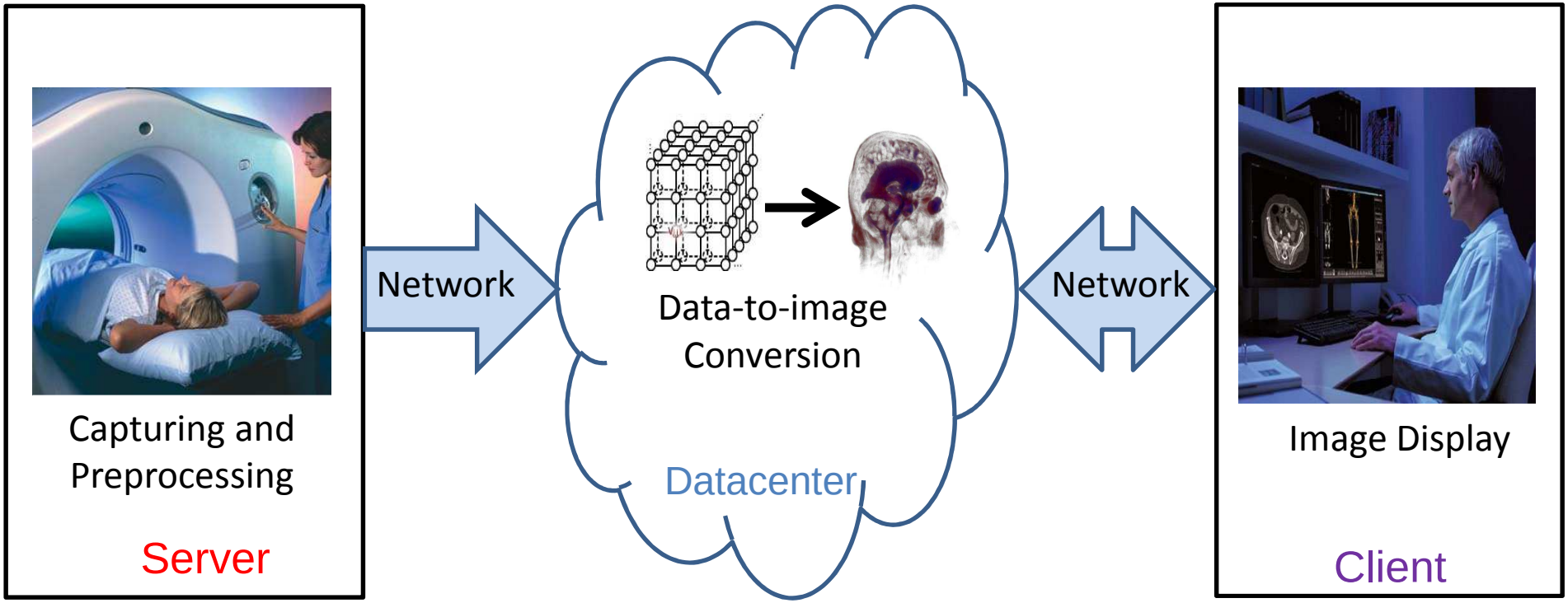
Image source: http://www.msimaging.com/Content/themes/MSI/images/cloud-based-software-image-silo-cloud-file.jpg

Cloud-based Multimedia Storage and Processing



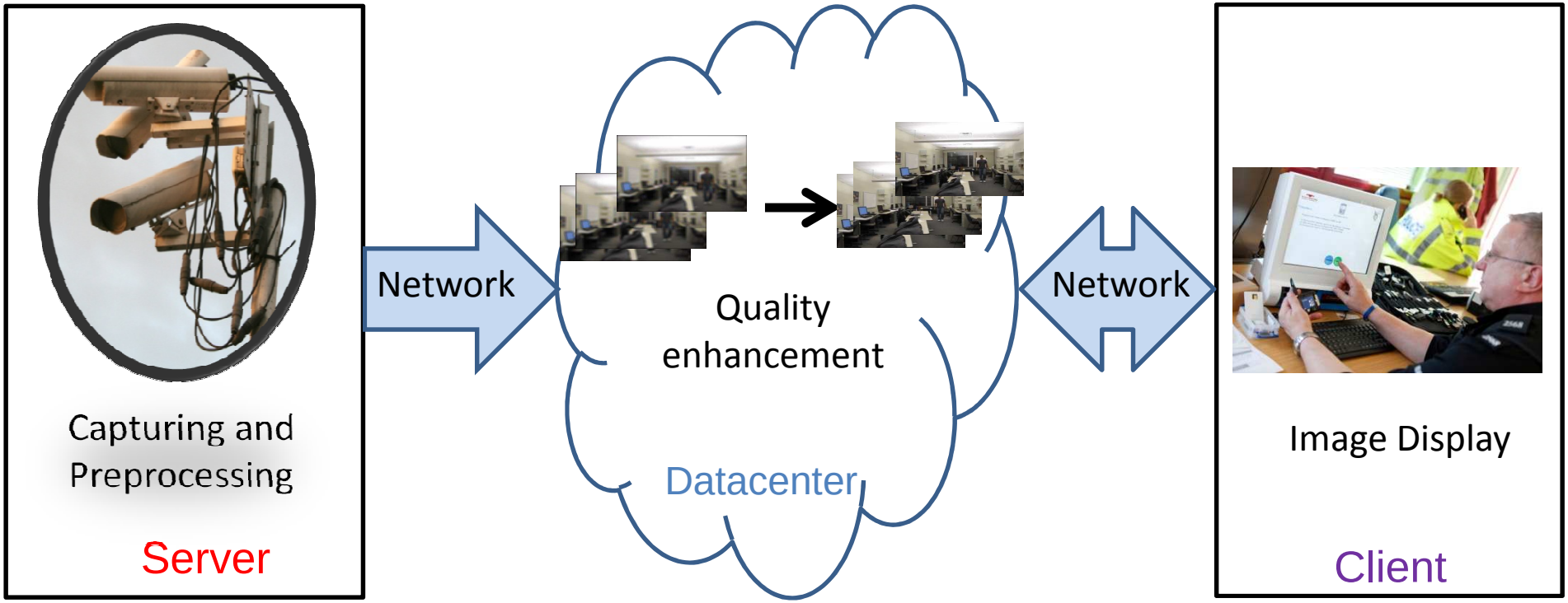
2D Image Visualization

Cloud-based Multimedia Storage and Processing



3D Image Visualization

Cloud-based Multimedia Storage and Processing



Surveillance Video Quality Enhancement

Cloud-based Multimedia Storage and Processing

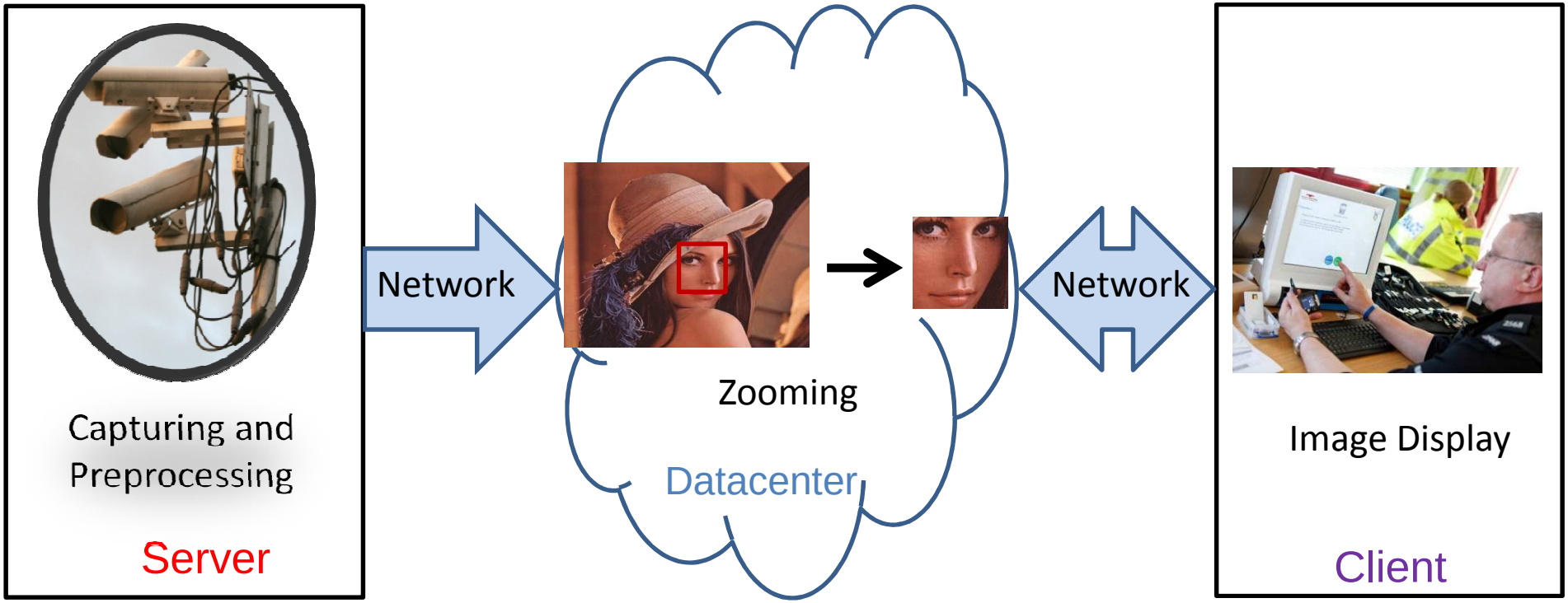


Image Zooming and Cropping

Security and Privacy Challenges in Cloud-based Storage and Processing

- How many of you mind if your medical image is available to an adversary?

- What can an adversary do with an image?

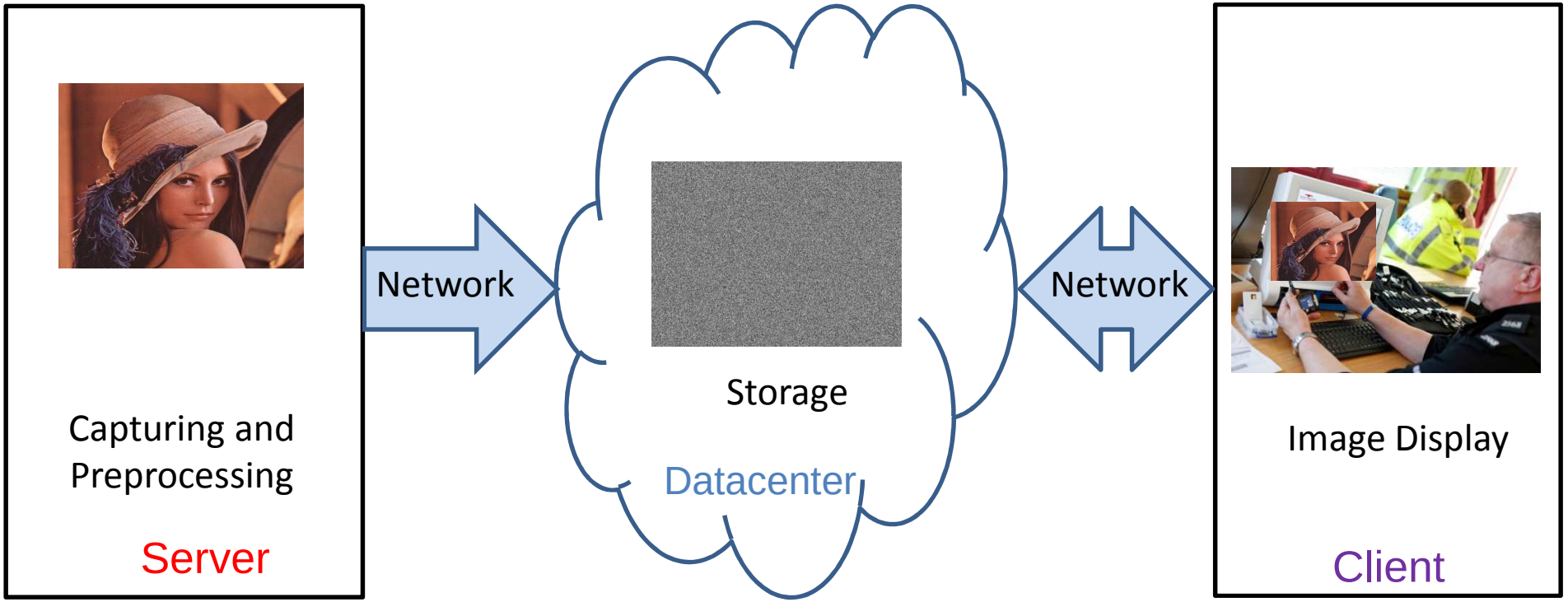
Image source: http://greenberg-art.com/.Toons/Toons,%20social/ qqxsgMedical%20privacy.gif

Rest of the talk

- Introduction and Motivation
- **Addressing the Challenges**
  - Finding a Cryptosystem
  - Using Real Numbers in a Cryptosystem
- Three Frameworks
  - Secure Cloud-based Image Scaling/Cropping
  - Secure Cloud-based Pre-classification Volume Ray-casting
  - Secure Cloud-based Surveillance Video Enhancement
- Conclusions

Smoking is not good for health

Security and Privacy Challenges: Secure Storage over Cloud



Encryption techniques – Watermarking – Secret sharing

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Security and Privacy Challenges: Insecure Processing over Cloud

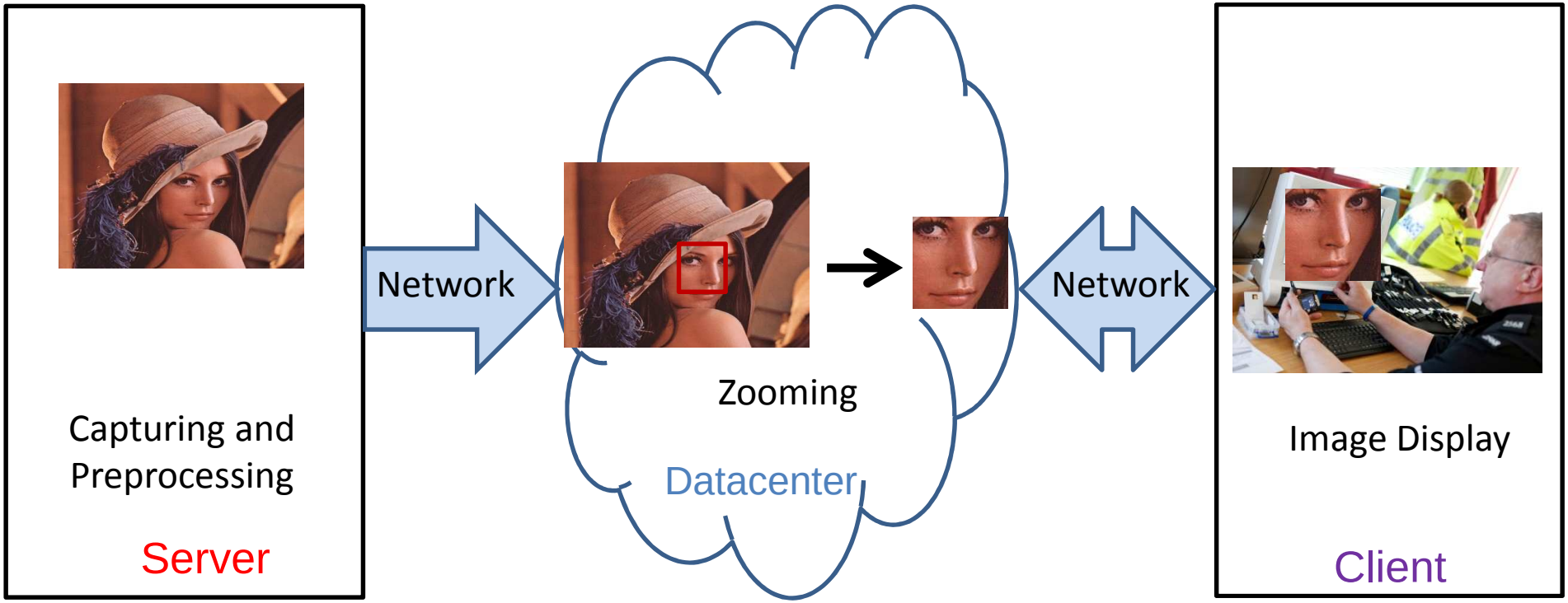

Image Zooming and Cropping on Original Data

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Security and Privacy Challenges: Secure Processing over Cloud

Still to be addressed

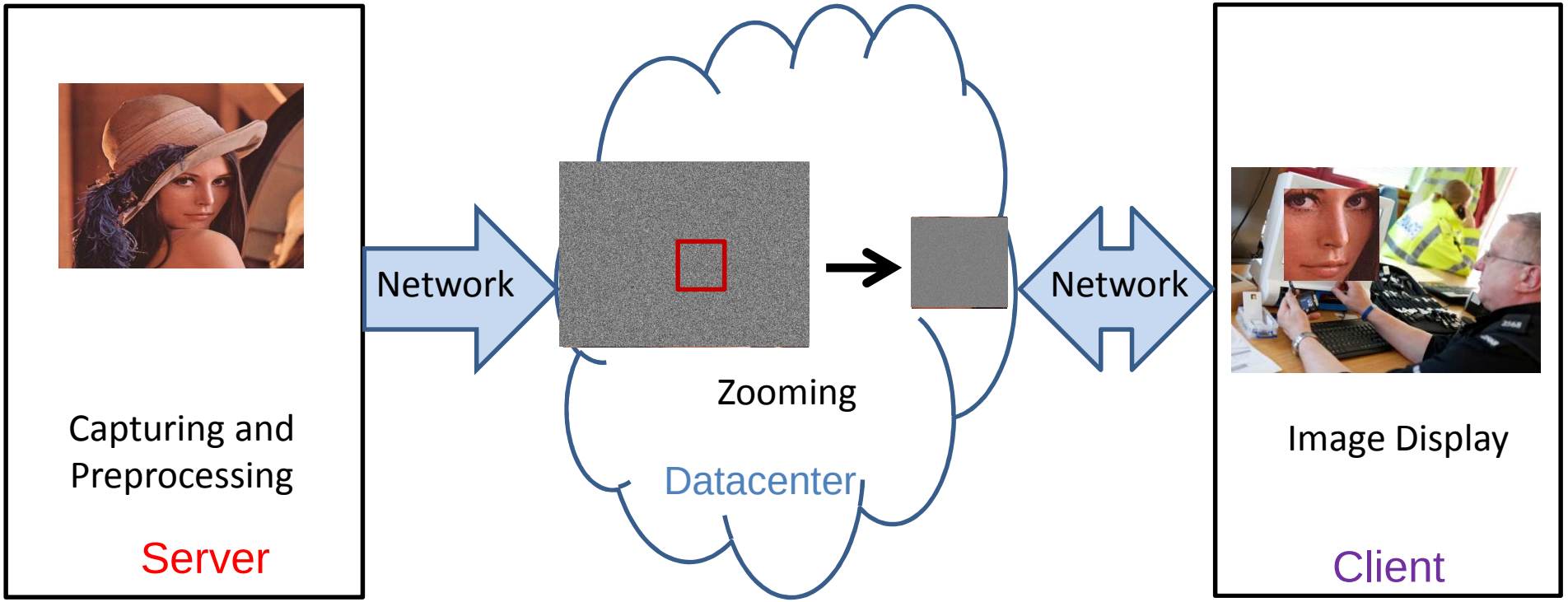

Image Zooming and Cropping on Encrypted Data

Our Objective: Secure Cloud-based Multimedia Processing

- Confidentiality
- Integrity
- Availability
- Privacy

Smoking is not good for health

Our Objective: Secure Cloud-based Multimedia Processing

- Confidentiality
- Integrity
- Availability
- Privacy
- Computational Efficiency
- Bandwidth Efficiency
- High Quality Image

Smoking is not good for health

Technical Challenges

- Finding a Cryptosystem
  - Fully homomorphic cryptosystem is not practical

    E(A) + E(B) = E(A+B)
  - Somewhat homomorphic cryptosystem cannot hide all information

Technical Challenges

- Finding a Cryptosystem
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    E(A) + E(B) = E(A+B)
  - Somewhat homomorphic cryptosystem cannot hide all information

- Using Real Numbers in a Cryptosystem
  - Modular prime operation of a cryptosystem is not compatible with real number operations of a data/image processing algorithm

Rest of the talk

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Finding a Cryptosystem

- Key Observations
  - Shamir's (*k*,*n*) Secret Sharing (SSS) or (*l*,*k*,*n*) Multi-Secret Sharing (MSS) can be used as principal cryptosystem
  - Other cryptosystems can be used to support operations that are not supported by SSS and MSS

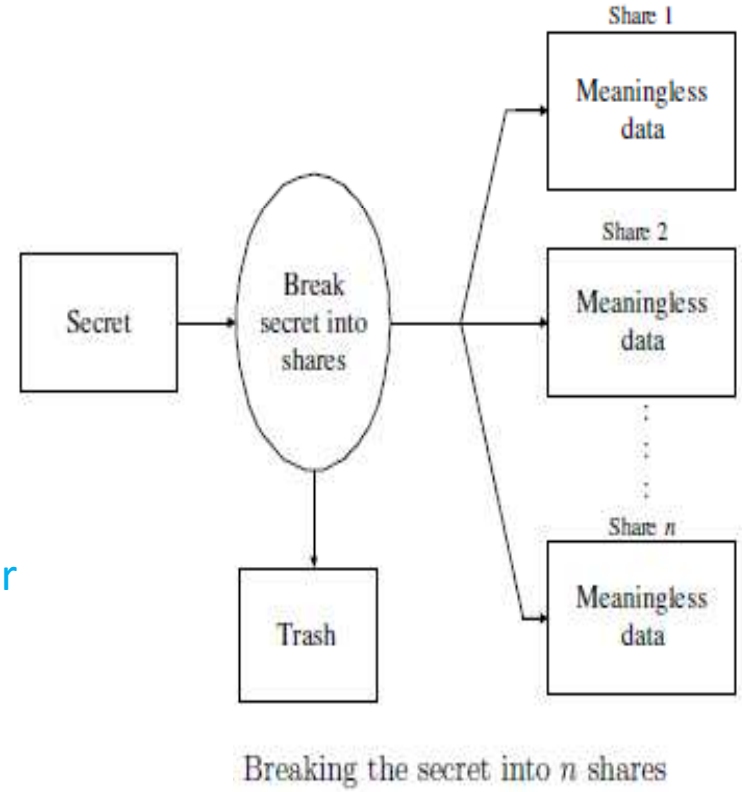
Finding a Cryptosystem

- Review of (k, n) SSS

Sharing a Secret

$$F(x) = \left(S + \sum_{i=1}^{k-1} a_i x^i\right) mod\ q$$

Secret — Random Number — Prime Number



Breaking the secret into n shares

Finding a Cryptosystem

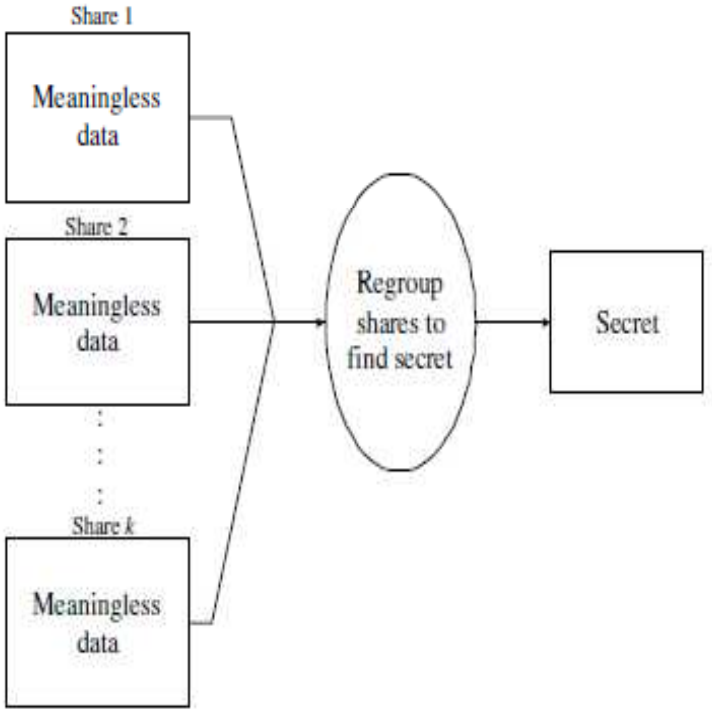
- Review of (k, n) SSS

Reconstructing a Secret

$$L(x) = \left(\sum_{i=0}^{k-1} F(i)\, t_i(x)\right) mod\ q$$

$F(i)$: i^{th} Share

$t_i(x)$: $\prod_{j=0, j\neq i}^{k-1} \frac{x - x_j}{x_i - x_j}$



Reconstructing the secret using $k \leq n$ shares

Finding a Cryptosystem

- Review of (*l*, *k*, *n*) MSS

Sharing a Secret

$$F(x) = \left(\sum_{i=0}^{l-1} s_i x^i + \sum_{i=l}^{k-1} a_i x^i\right) mod\ q$$

s_i : i^{th} Secret

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Using Real Numbers in a Cryptosystem

- Excluding Modular Prime Operation from the Cryptosystem
  - Example: Shamir's secret sharing $F(x) = S + \sum_{i=1}^{k-1} a_i x^i$

  - Side Effect: Degradation of Security
    - ✓ For $(2, n)$ Shamir's secret sharing, the probability of finding the secret from $F(x_i)$ is:
      With mod q: $1/q$
      Without mod q: $INT(x_i / F(x_i))$

Using Real Numbers in a Cryptosystem

- Modifying Real number to an Integer
  - $R(S,d) = \text{round}(S,d) \times 10^d$

Integer Representative

Obtained by rounding off S by d decimal places

Using Real Numbers in a Cryptosystem

- Modifying Real number to an Integer
  - $R(S,d) = round(S,d) \times 10^d$

Integer Representative

Obtained by rounding off S by d decimal places

  - Side Effect: Roundoff Error
    - ✓Is bounded by $\pm (5 \times 10^{-(d+1)})$
    - ✓Expands with addition and scalar multiplication

Rest of the talk

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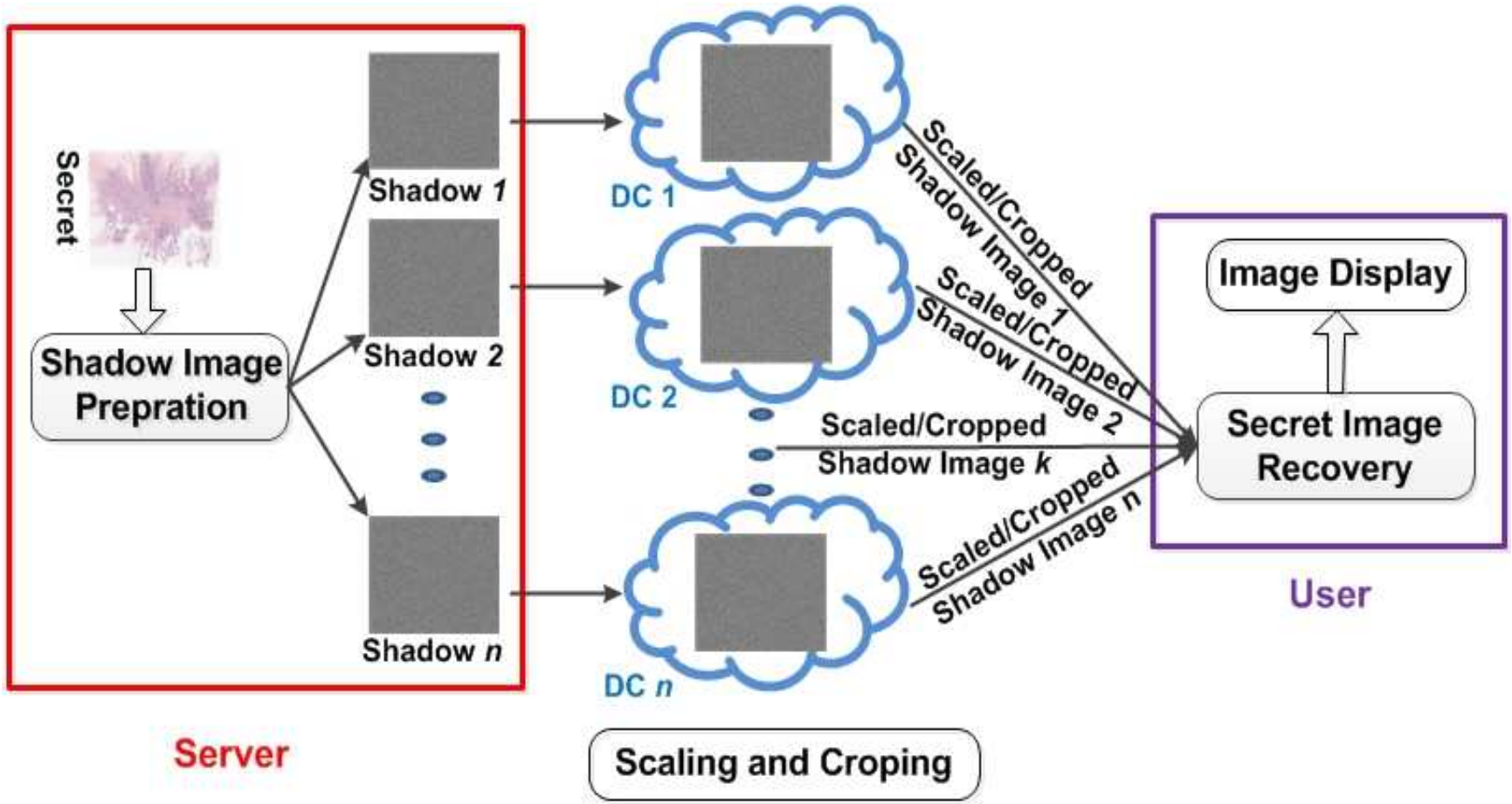
Secure Cloud-based Image Scaling/Cropping

- Why scaling/cropping in data centers?
  - Streaming a large image
    - Downloading a large image (e.g. histopathology image that can be 40 GB in size 80000 × 80000 in dimension) is not feasible
  - Previewing an image before viewing
- Why dynamic scaling/cropping on shadow (or hidden) images?
  - Pre-cropping required additional data to be sent
  - Pre-scaling cannot ensure step-less zooming

M. Mohanty, W.-T. Ooi and P. K. Atrey. **Scale me, crop me, know me not: Supporting scaling and cropping in secret image sharing**. *IEEE International Conference on Multimedia and Expo (ICME'2013)*, July 15-19, 2013, San Jose, CA, USA.

Secure Cloud-based Image Scaling/Cropping

- Architecture and Workflow



Secure Cloud-based Image Scaling/Cropping

- Proposed Secret Image Sharing Scheme
  - Inter-pixel correlation is hidden by using a set of random numbers as coefficient in the secret sharing polynomial
  - (3,*k*,*n*) MSS

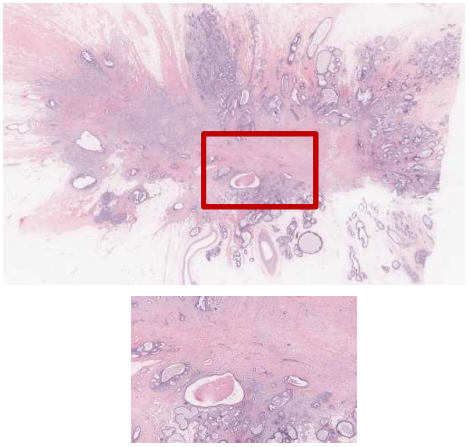
$$H(x) = \left(R + Gx + Bx^2 + \sum_{i=3}^{k-1} a_i x^i \right) \bmod q$$

Secure Cloud-based Image Scaling/Cropping

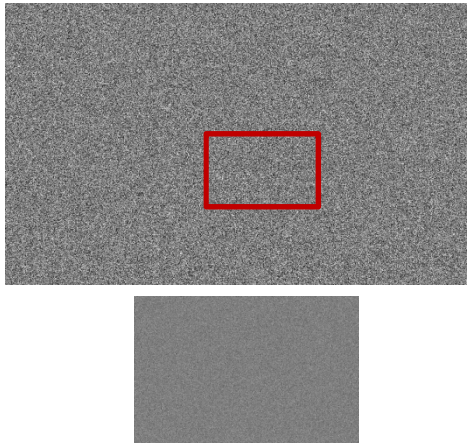
- Experiments
  - Server, datacenters, and user are simulated in a PC
  - Two test images
    - ✓A histopathology image (size 5.2 MB, dimension: 2756 × 3663)
    - ✓The *Lena* Image (size 205.5 KB, dimension: 512 × 512)

Secure Cloud-based Image Scaling/Cropping

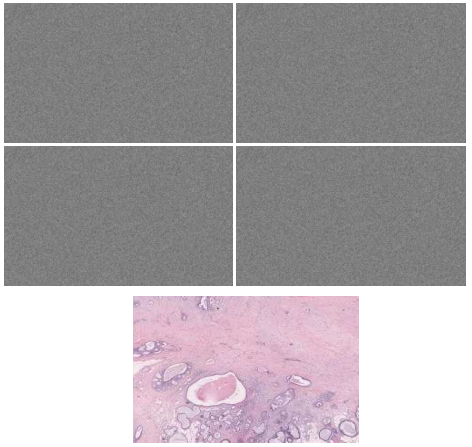
- Results: Scaling



Required



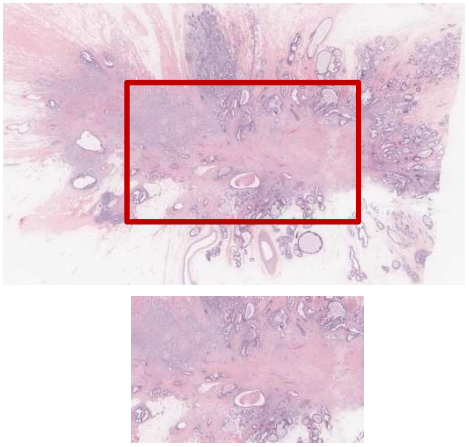
Zoomed Shadow Image



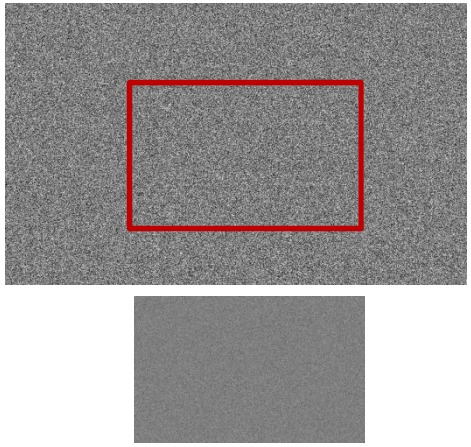
Recovered Zoomed Image

Secure Cloud-based Image Scaling/Cropping

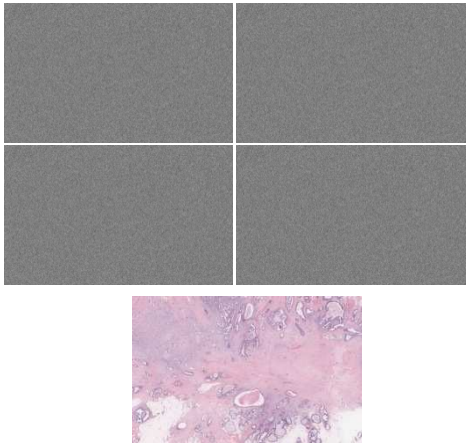
- Results: Cropping



Required



Cropped Shadow Image



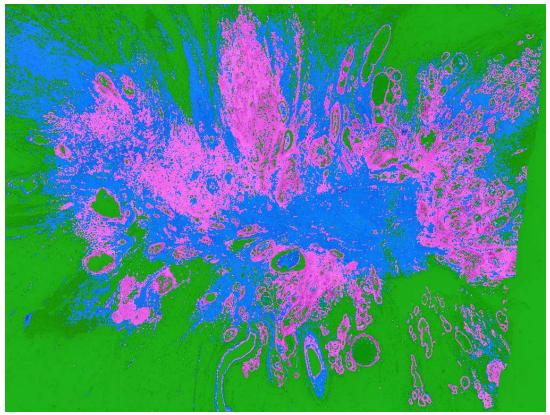
Recovered Cropped Image

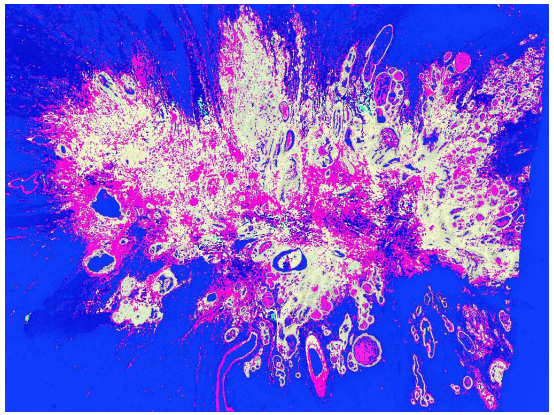
Secure Cloud-based Image Scaling/Cropping

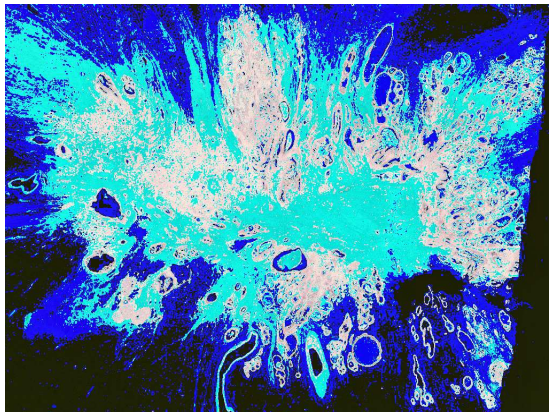
- Security Analysis
  - Confidentiality
    - ✓Perceptual security
    - ✓Multi-secret sharing is not perfectly secure

Secure Cloud-based Image Scaling/Cropping

- Security Analysis
  - Integrity
    - ✓if $n > k$, then ${}^{n}C_{k}$ ways to reconstruct an image







Corrupted shadow image(s) implies different reconstructed images

Secure Cloud-based Image Scaling/Cropping

- Performance Analysis
  - Data Overhead
    - ✓ $\frac{bk-24}{24}$ times more than the conventional streaming, where b is the number of bits required to represent q
    - ✓ For $d = 2$ and $k = 4$, 1.5 times more than the conventional
  - Computational Overhead
    - ✓ For a PC with Intel Core 2 Quad 2.83 Ghz processor and 4GB of RAM, approximately 76.35 ms is required to recover a 512 × 512 secret image (0.3 μs per pixel)

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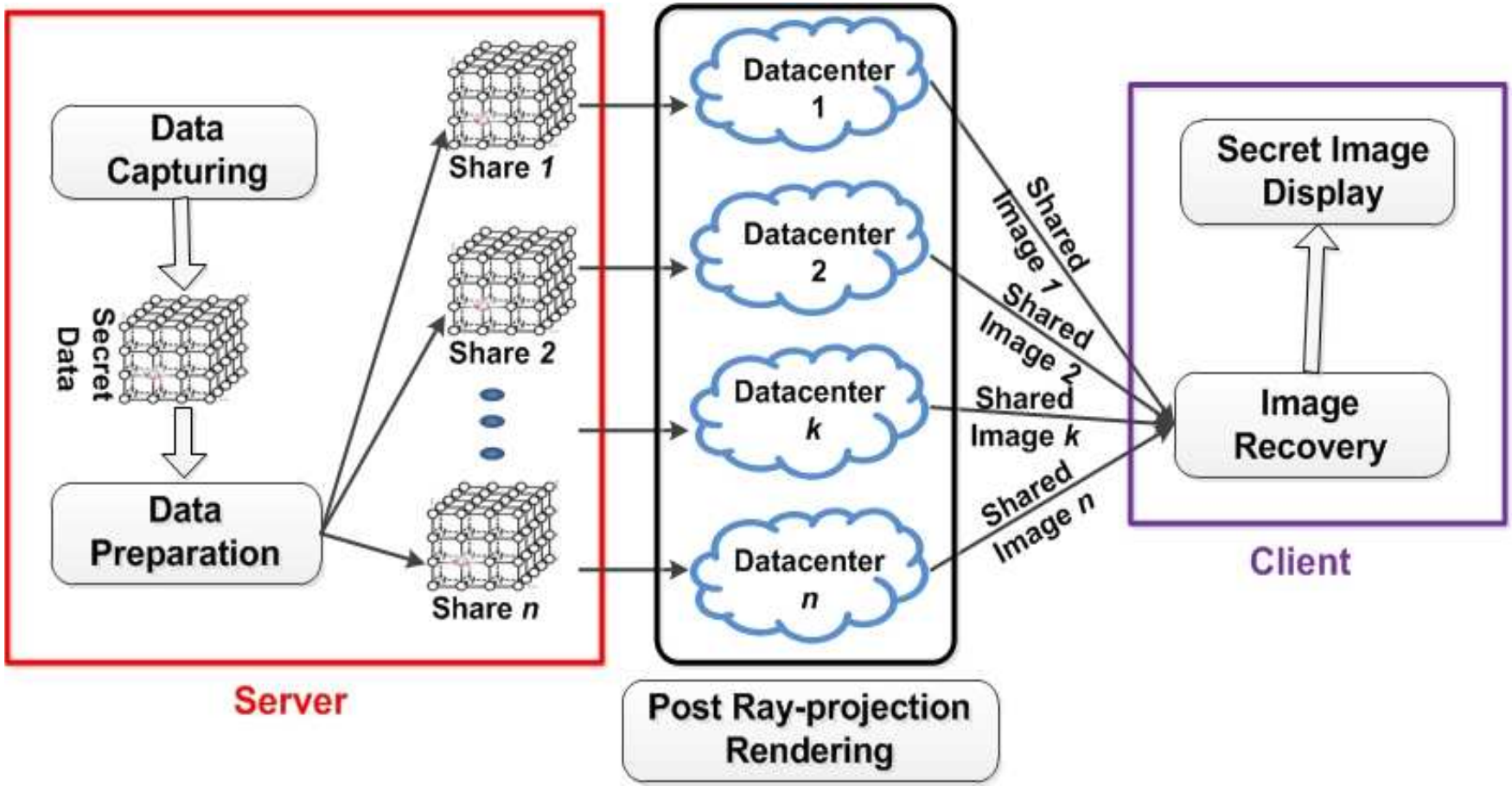
  - **Secure Cloud-based Pre-classification Volume Ray-casting**
  - Secure Cloud-based Surveillance Video Enhancement
- Conclusions

Secure Cloud-based Pre-classification Volume Ray-casting

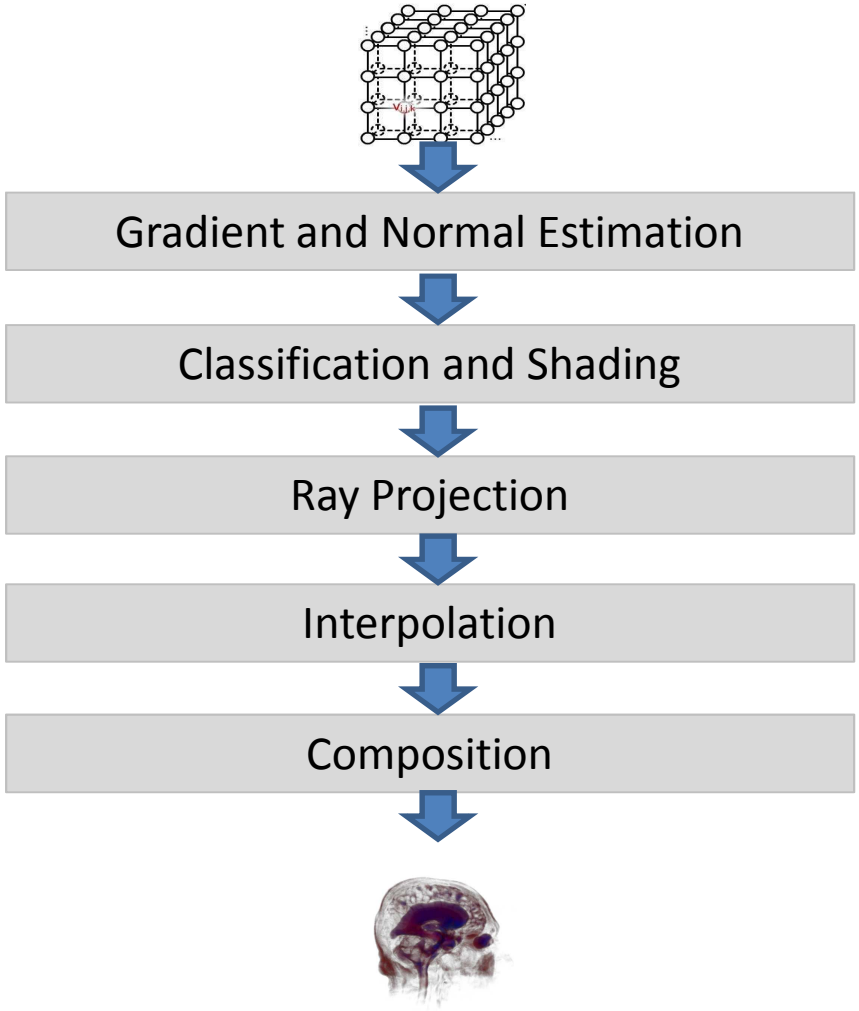
- Architecture and Workflow



M. Mohanty, P. K. Atrey and W.-T. Ooi. **Secure cloud-based medical data visualization**. *The ACM International Conference on Multimedia (ACMMM'12)*, October 29-November 2, 2012, Nara, Japan.

Secure Cloud-based Pre-classification Volume Ray-casting

- Review: Pre-classification Volume Ray-casting



Secure Cloud-based Pre-classification Volume Ray-casting

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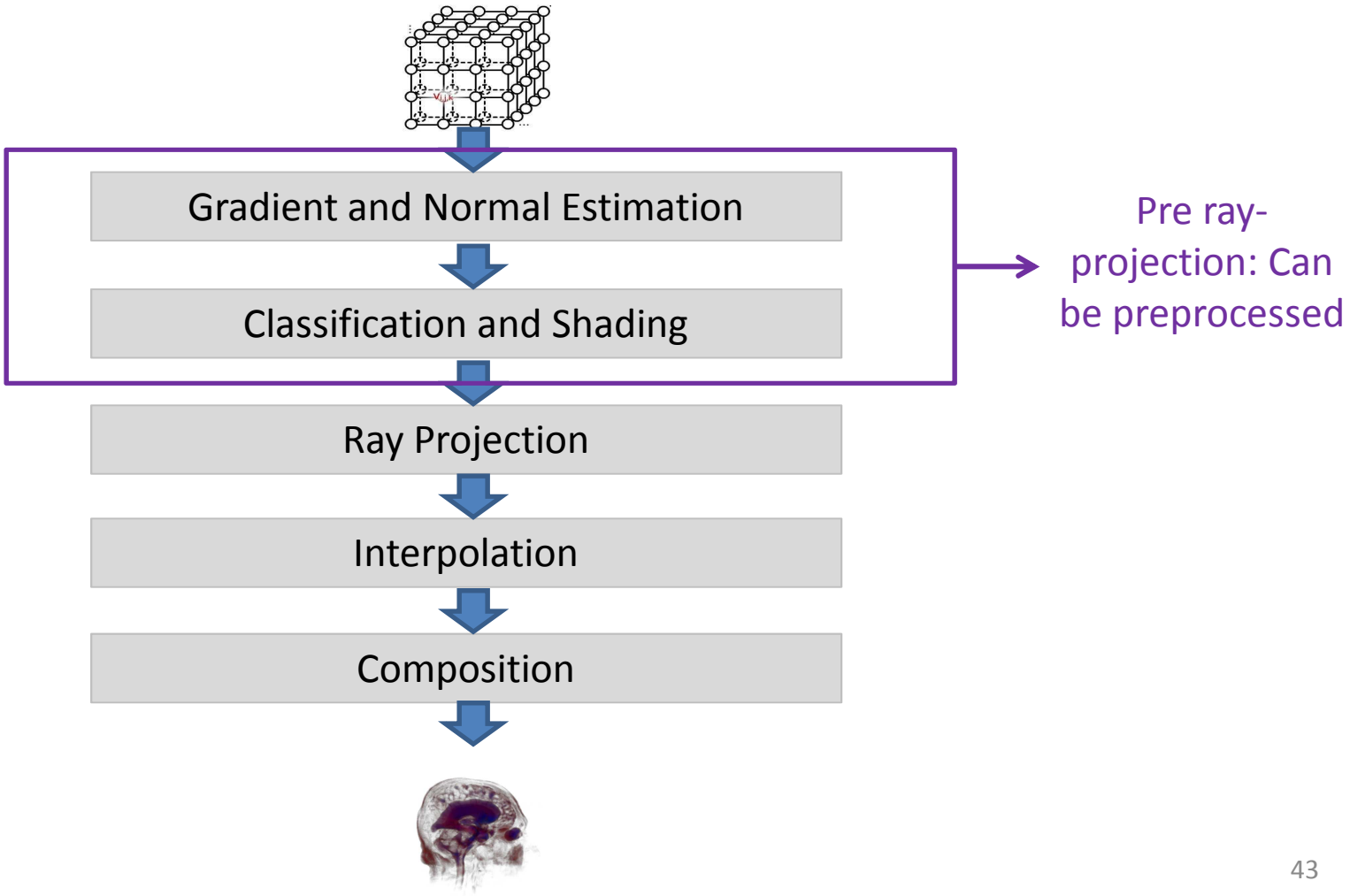

Secure Cloud-based Pre-classification Volume Ray-casting

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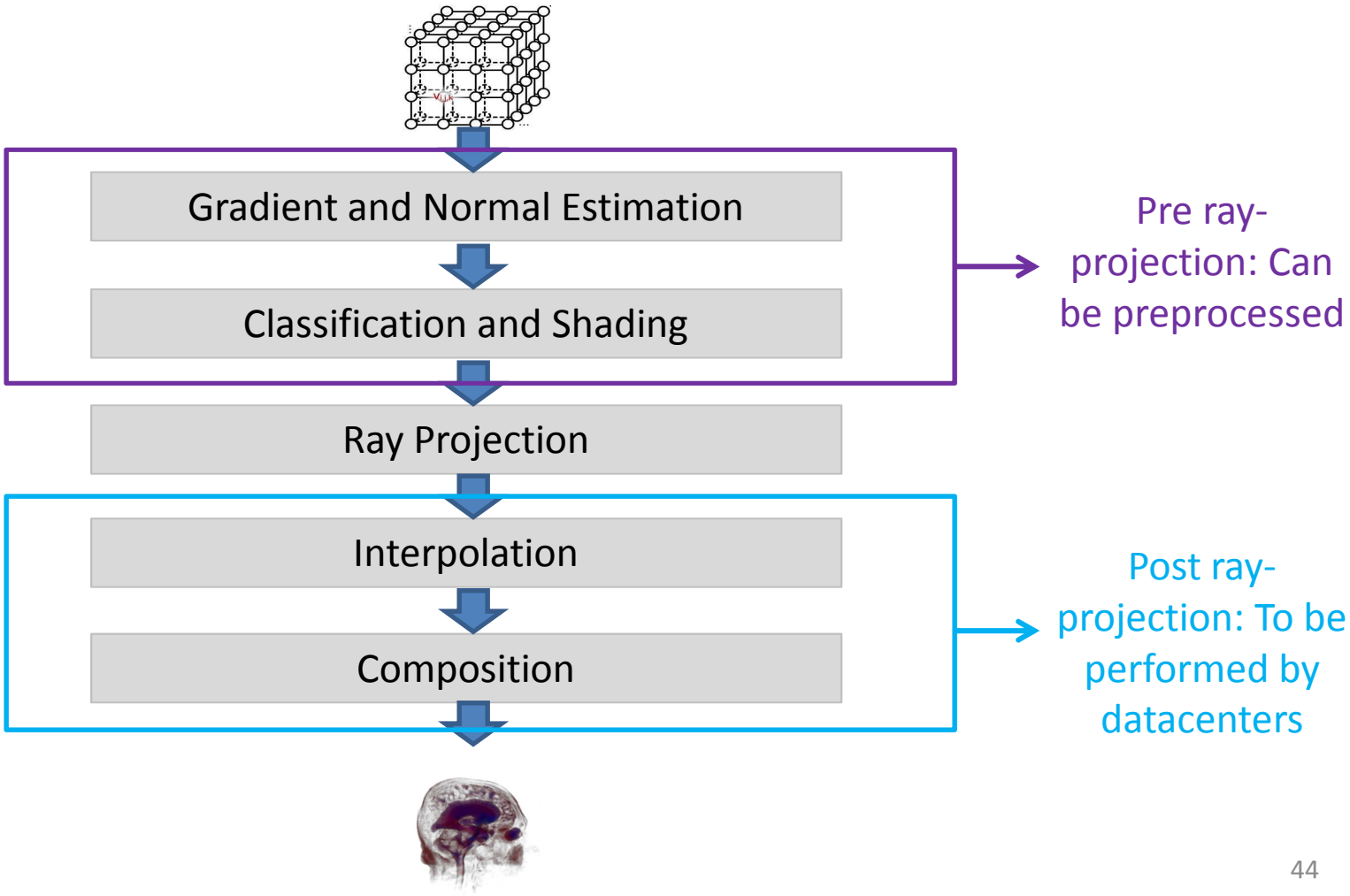
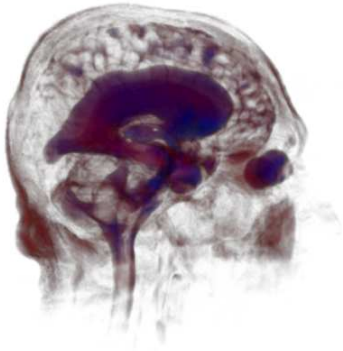
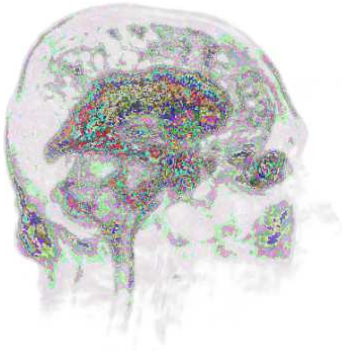


Secure Cloud-based Pre-classification Volume Ray-casting

- Securing Post Ray-projection
  - Hiding computation on colors



Original



Hidden Color

Not hiding computation on opacities

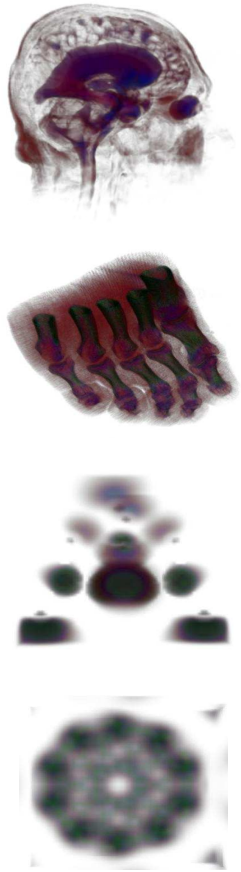
Secure Cloud-based Pre-classification Volume Ray-casting

- Experiment
  - Server, Datacenters, and Client are simulated in a PC
  - Customized VTK *5.8.0*
    - ✓ Pre-classification volume ray-casting
    - ✓ Integrated (3,5) Secret Sharing

Secure Cloud-based Pre-classification Volume Ray-casting

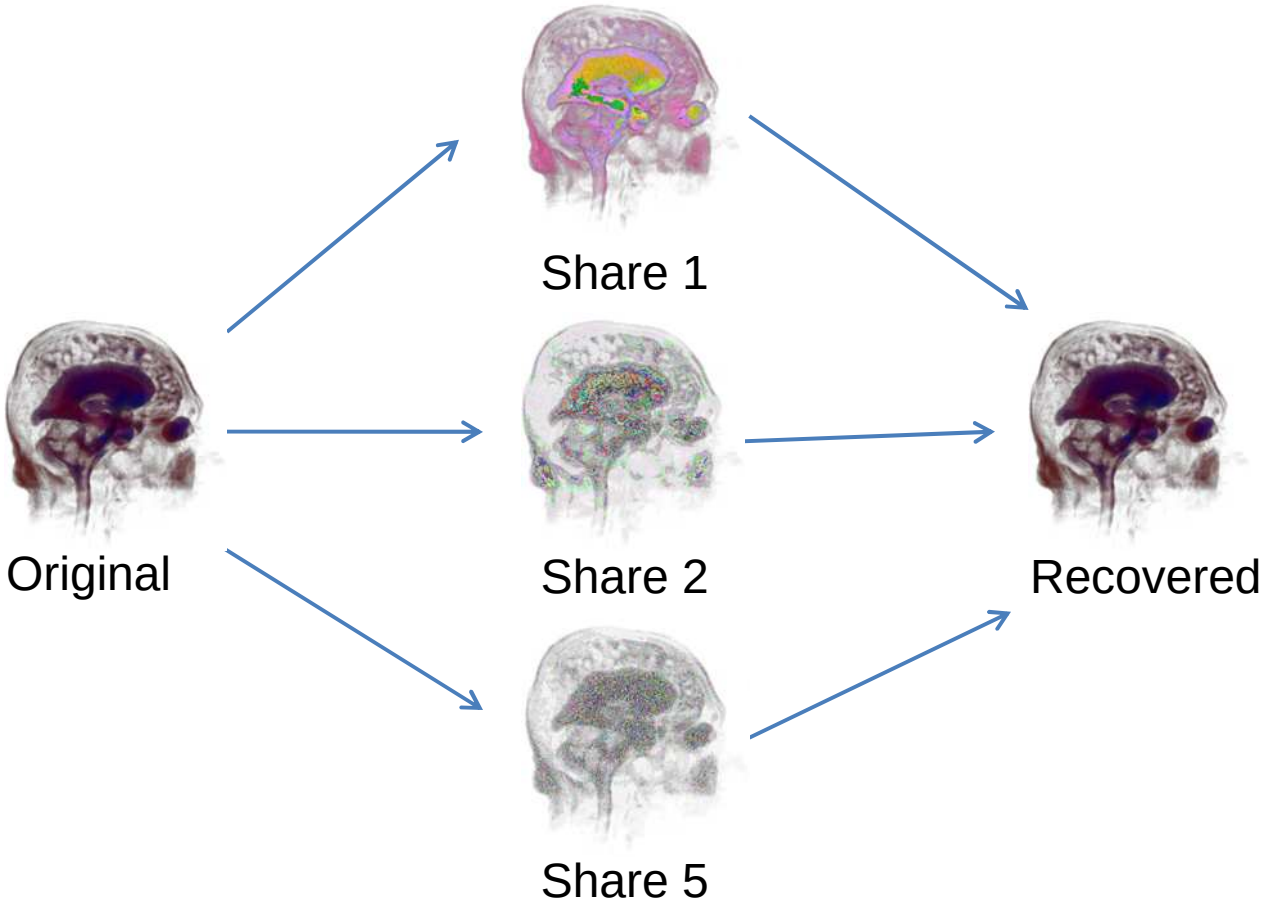
- Data Set

	Dimension	Size
Head	256 X 256 X 124	7.8 MB
Foot	256 X 256 X 256	16 MB
Iron port	68 X 68 X 68	307.3 KB
Bucky	32 x 32 X 32	32.2 KB



Secure Cloud-based Pre-classification Volume Ray-casting

- Results: Single View Point



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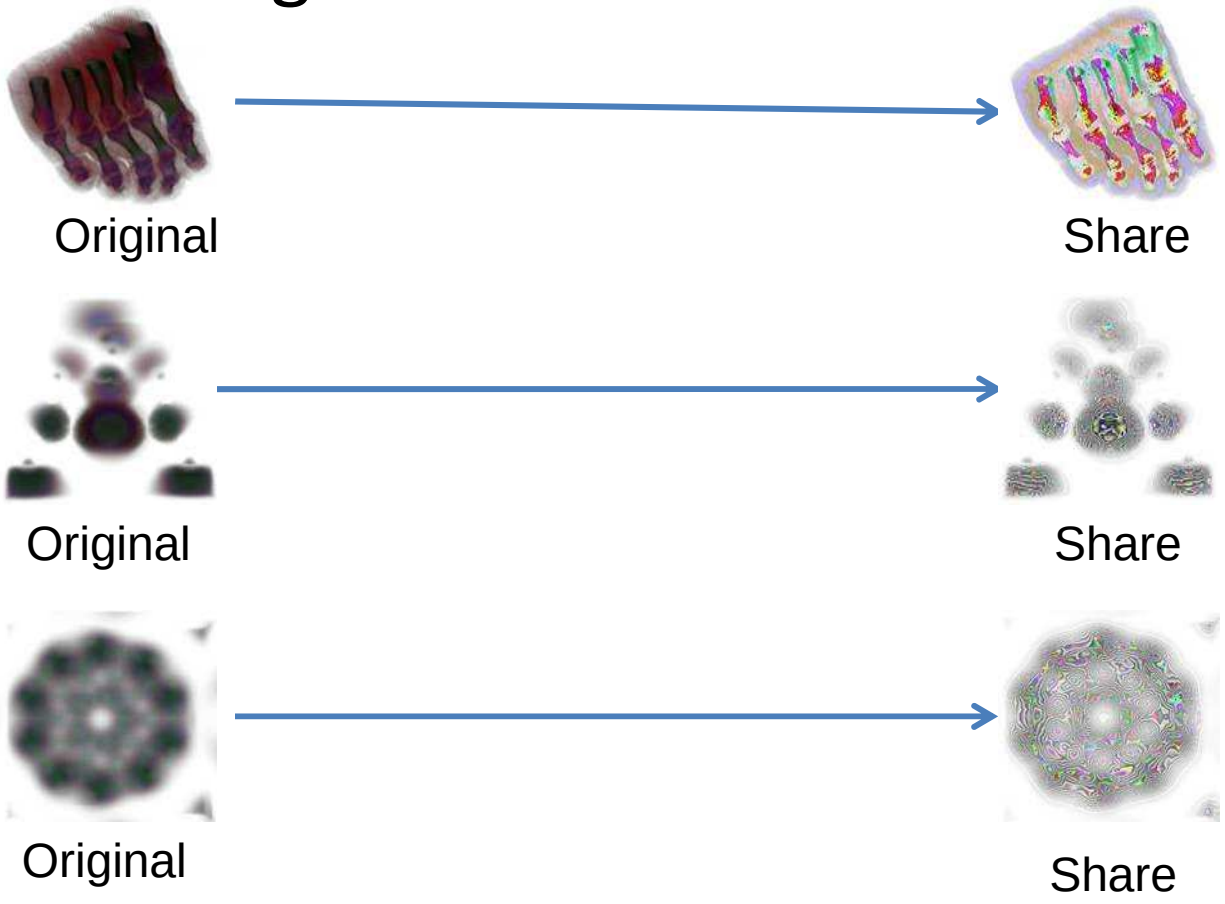
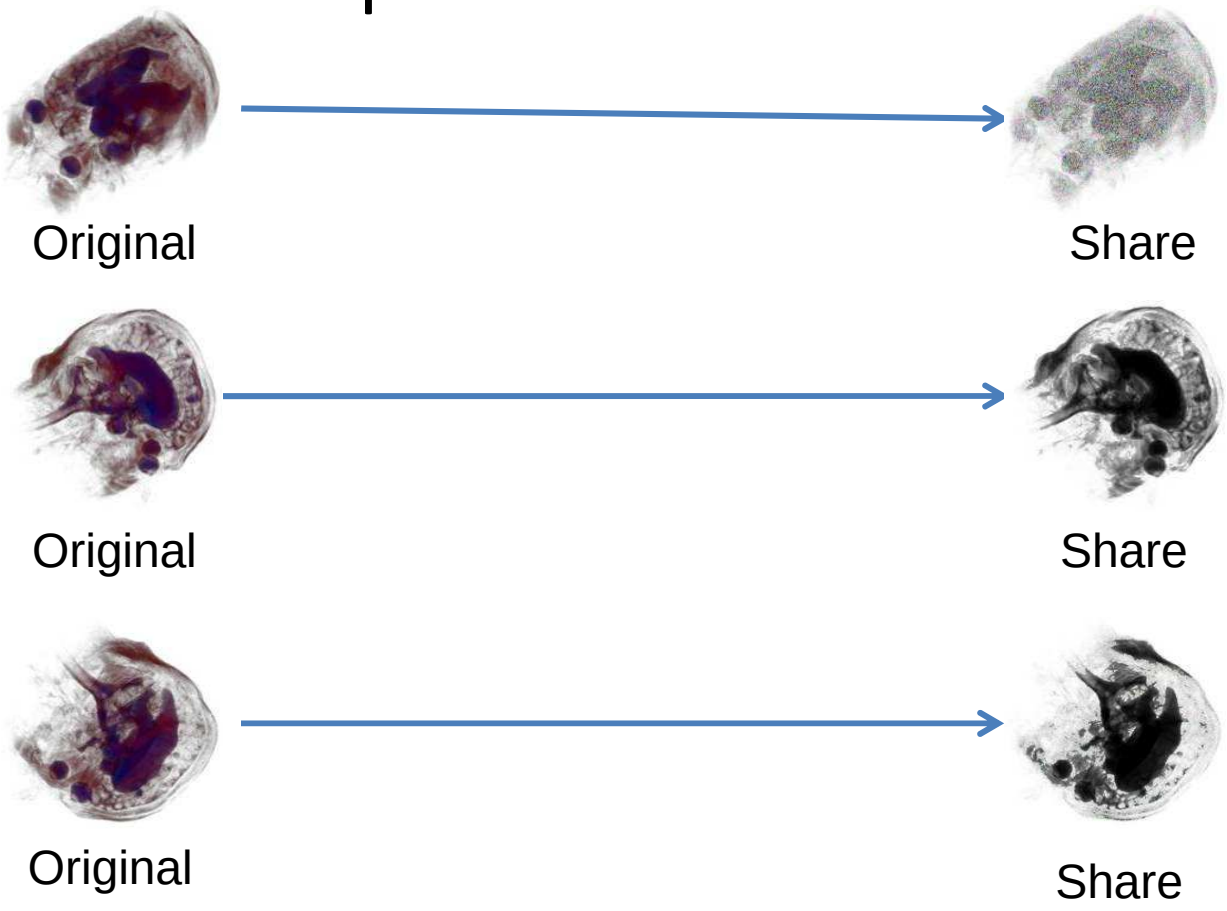


Secure Cloud-based Pre-classification Volume Ray-casting

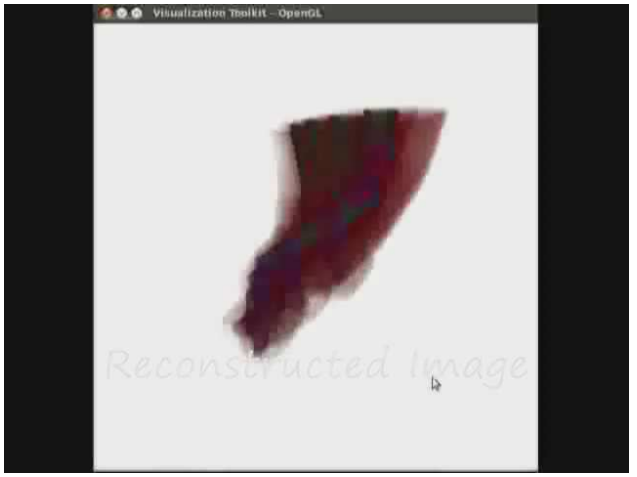
- Results: Multiple View Point



Secure Cloud-based Pre-classification Volume Ray-casting

Head MRI volume data

Foot volume data



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  - **Secure Cloud-based Surveillance Video Quality Enhancement**
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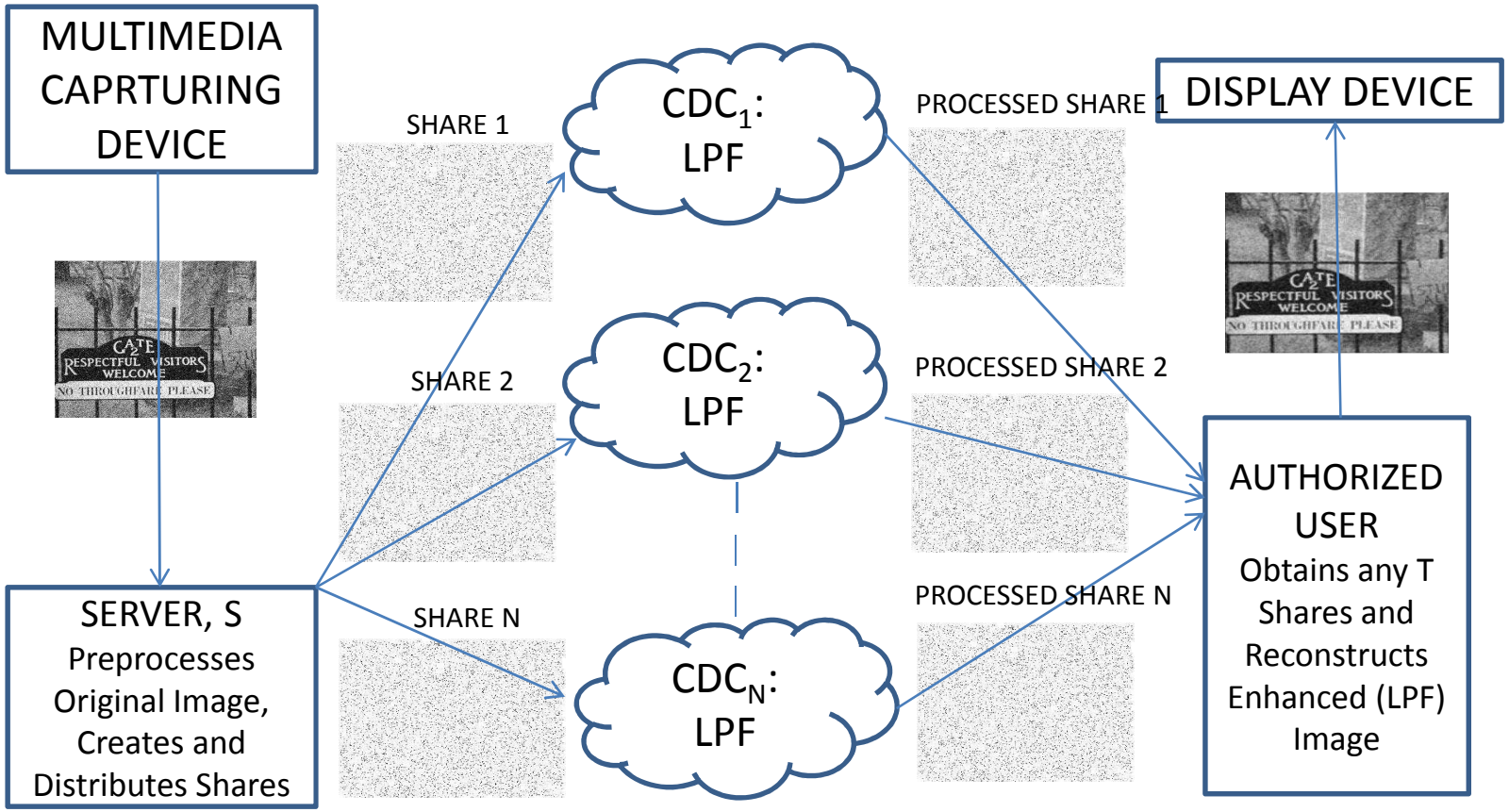
Encrypted-domain Video Quality Enhancement over Cloud

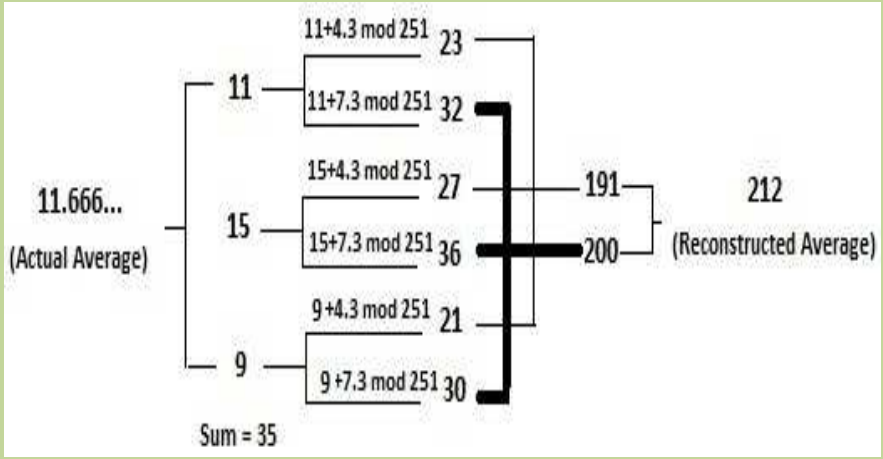
- Architecture and Workflow



A. Lathey, P. K. Atrey and N. Joshi. **Homomorphic low pass filtering on encrypted multimedia over cloud**. *IEEE International Conference on Semantic Computing (ICSC'2013)*, September 2013, Irvine, CA, USA.

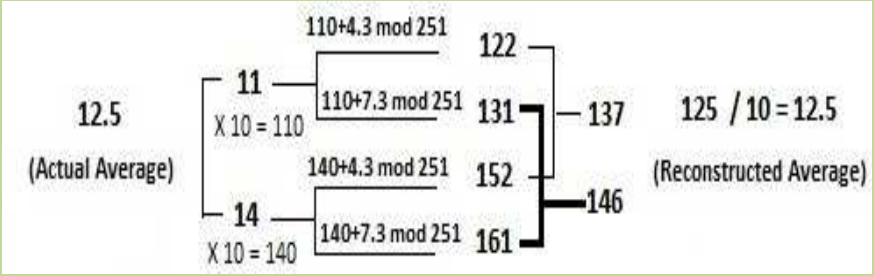
THE PROBLEM:

Non-terminating averaged value

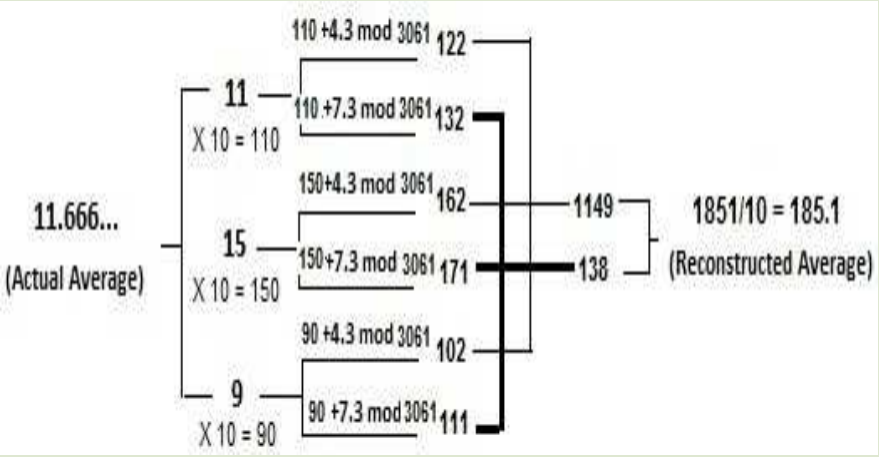


SOLUTION BASED ON PREVIOUS METHOD

Multiply each pixel intensity value by a factor of 10^d, where d depends upon the precision of the desired decimal digits up to which we want to process the real numbers. The prime number should always be chosen as greater than $(255+51\times10^d)\times10^d$

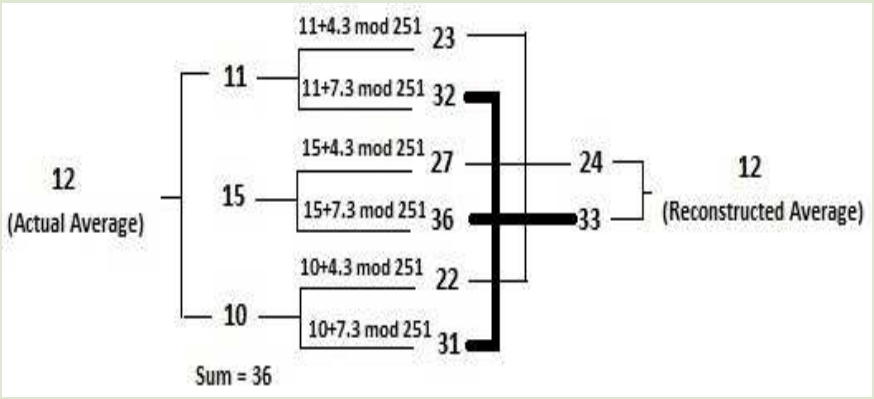


APPLIED TO THE PROBLEM:



PROPOSED SOLUTION:

pre-process the image data in such a way that averaging is performed on completely divisible values only.



Encrypted-domain Video Quality Enhancement over Cloud

Scheme I: Multiplying each original intensity value by the mask size, (*m*×*n*). In other words, convert each pixel *I(u,v)* to a multiple of (*m*×*n*) by,

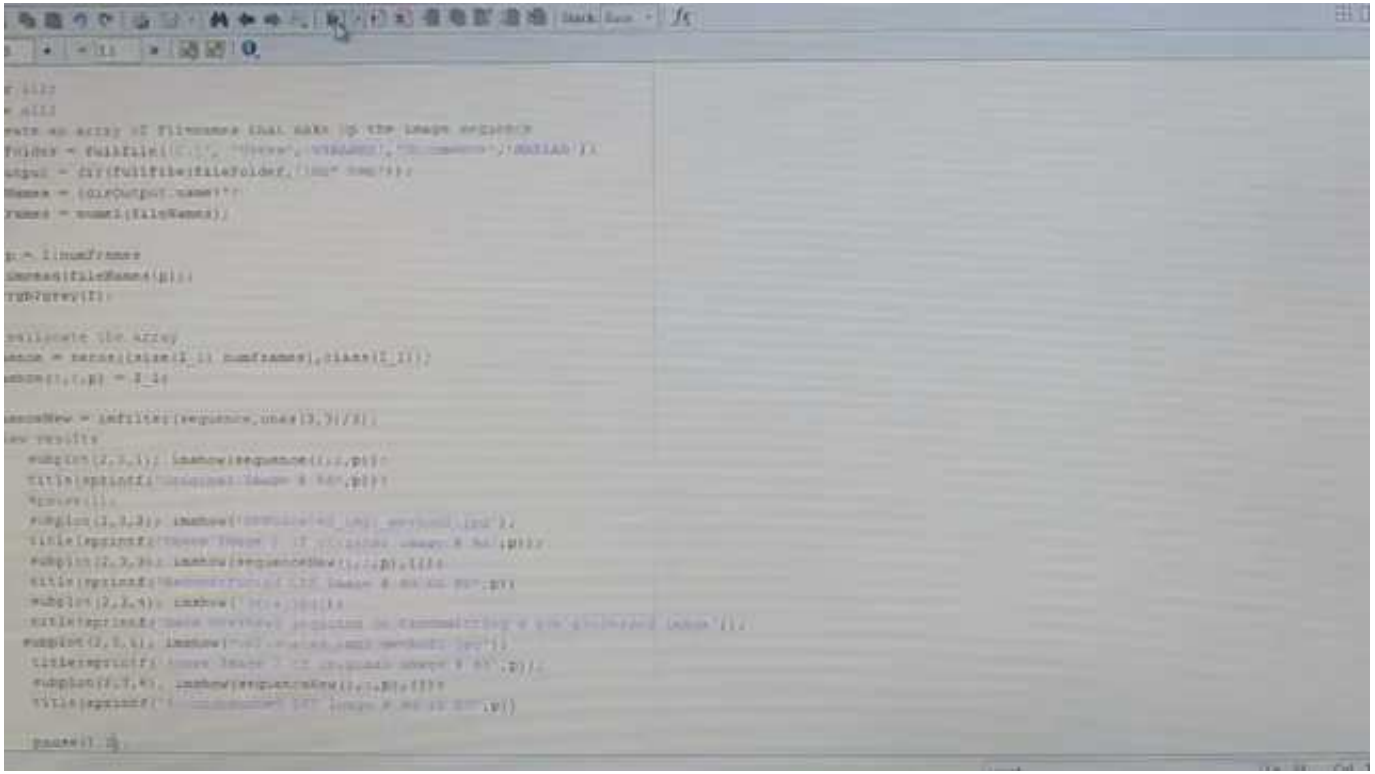
$$I^{'}(u,v) = I(u,v) \times (m \times n)$$

Scheme II: Changing each original intensity value to the nearest multiple of (*m*×*n*) by adding or subtracting a maximum of values to or from its current value, where the range of lies between 1 and Γ m-n/2⍰. In other words, convert each pixel I(u, v) to a multiple of (*m*×*n*) by,

$$I^{'}(u,v) = I(u,v) \pm \Delta$$

Encrypted-domain Video Quality Enhancement over Cloud

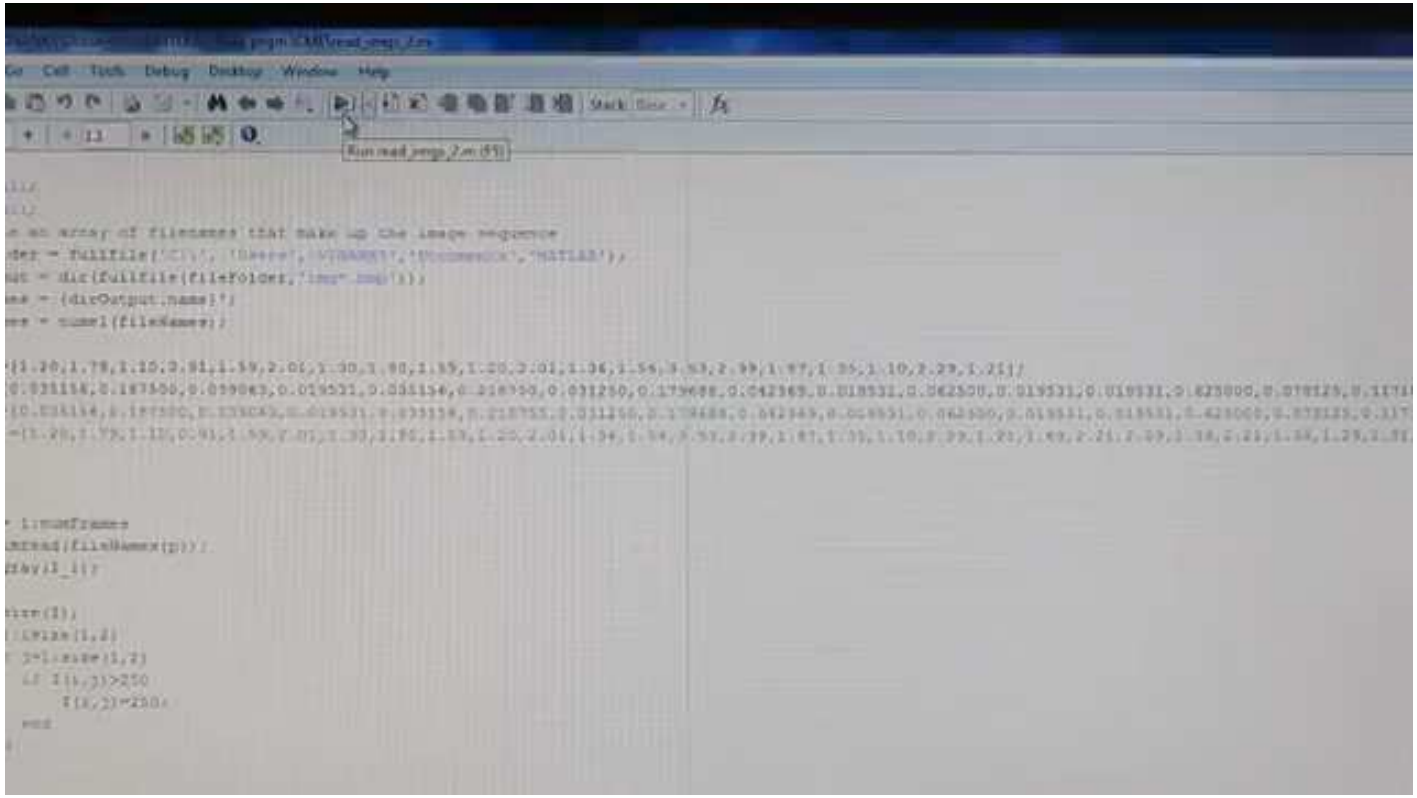
- Results – Scheme 1



http://www.youtube.com/watch?v=hJg67v3IbmU&feature=youtu.be

Encrypted-domain Video Quality Enhancement over Cloud

- Results – Scheme 2



http://www.youtube.com/watch?v=TqRHJ6KrZY0&feature=youtu.be

Conclusions

- Addressed incompatibility of a cryptosystem with real number
- Proposed three frameworks using Shamir's secret sharing as principal cryptosystem
- More secure cloud-based systems can be built using somewhat homomorphic cryptosystems

Publications

- A. Lathey, P. K. Atrey and N. Joshi. **Homomorphic low pass filtering on encrypted multimedia over cloud**. *IEEE International Conference on Semantic Computing (ICSC'2013)*, September 2013, Irvine, CA, USA.

- M. Mohanty, W.-T. Ooi and P. K. Atrey. **Scale me, crop me, know me not: Supporting scaling and cropping in secret image sharing**. *IEEE International Conference on Multimedia and Expo (ICME'2013)*, July 15-19, 2013, San Jose, CA, USA.

- M. Mohanty, P. K. Atrey and W.-T. Ooi. **Secure cloud-based medical data visualization**. *The ACM International Conference on Multimedia (ACMMM'12)*, October 29-November 2, 2012, Nara, Japan.

What Next?

- This is not the end of the world.

- Need to examine the suitability of the proposed frameworks in other cloud-based applications such as:
  - Scaling/cropping on compressed images/videos
  - Compression in encrypted domain
  - Processing other media e.g. text documents and audio