Content-based image retrieval (CBIR) refers to the use of visual features for images retrieval, and has become an attractive approach to managing biomedical image achieves. However, existing CBIR systems are typically designed for 2D single-modality imaging, and are restricted when multi-dimensional images are considered. With the advances in imaging scanners, image complexity and magnitude have rapidly expanded in both the temporal (time) and spatial (space) dimensions, i.e., dynamic PET provides physiological functions of the human body acquired in 3D volumes over multiple time sequences, and dual-modality imaging scanners that sequentially acquire co-aligned functional (PET) and anatomical (CT) images. This manuscript summarizes research in CBIR of multi-dimensional biomedical images with focuses on the feature extraction and retrieval techniques that utilize the information available in the image's multi-dimensional data spaces. Applications of multi-dimensional CBIR will be exemplified with our ongoing studies with 4D dynamic PET and dual-modal PET/CT images.

Keywords: content-based image retrieval; dynamic PET; functional imaging; multi-dimensional imaging; PET/CT; space dimension; time dimension
sufficiently describe the rich visual properties or features of the image content and therefore impose significant limitations on image retrieval capabilities (Lehmann, Güld, Thies, Fischer, Spitzer, Keyser, et al., 2004; Müller, Michoux, Bandon, & Geissbühler, 2004).

Content-based image retrieval (CBIR) refers to the use of visual attributes of the image for retrieval from an image database, and has become an attractive technique in managing large medical image databases (Müller, et al., 2004; Shyu, Brodley, Kak, Kosaka, Aisen, & Broderick, 1999; Yu, Chiang, & Hsieh, 2005). Recent years has resulted in the introduction of many domain-specific CBIR solutions for a large array of medical imaging modalities (Shyu, et. al, 1999; Yu, et. al, 2005; Kim, Cai, Feng, & Wu, 2006), such as for high-resolution lung CT (Shyu, et. al, 1999) and microcalcification from mammography (El-Naga, Yang, Galasanos, Nishikawa, & Wernick, 2004), as well as methods to automatically categorize medical images as in Lehmann, Güld, Deselaers, Keyser, Schubert, Spitzer, et al., (2005). However, the majority of existing CBIR systems are typically designed for two-dimensional (2D) slices, even though the images acquired were multi-dimensional, and are thus not taking full advantage of the information available in all the image dimensions. Modern biomedical imaging scanners have the capability to acquire images in multiple dimensions – 3D spatial images (space) such as with computed tomography (CT), and magnetic resonance imaging (MRI); in dynamic temporal sequences (time), i.e., dynamic positron emission tomography (PET), functional MRI, and ultrasound; as well as in combined dual-modality imaging e.g., sequentially acquired and co-aligned PET/CT. Because dual-modality imaging is the combination of two full 3D image volumes, it can be considered as four-dimensional (4D), where the PET volume with lower resolution is resampled to that of the higher resolution CT. These multi-dimensional biomedical imaging modalities are requiring new approaches to fully utilize all the information within the image data for content-based retrieval, while at the same time introducing new challenges and opportunities for CBIR research and development. There have been numerous researches that investigated the use of the entire range of information within the multi-dimensional images for feature extraction, representation, and retrieval.

In a study by Shyu et al. (1999), delineations of pathology bearing regions were manually defined by physicians, along with a set of anatomical landmarks on a key frame – a single image slice selected from an image stack. Such a key frame was used to extract features that represented an entire image volume for content-based retrieval of high resolution CT (lung) image. Together with the key frames, other contiguous images which carry important diagnostic meaning, i.e., information regarding the 3D extends and shape of the pathology were also indexed into the database.

Liu, Lazar, Rothful, Dellaert, Moore, Schneider, et al. (1998) introduced a content-based retrieval technique based on 3D ideal midsagittal plane (iMSP) features for retrieving 3D CT neuroimages of hemorrhage (blood), bland infarct (stroke), and normal brain structures. A basic observation from neuroradiologic imaging is that normal human brains exhibit an approximate bilateral symmetry that is often absent in pathological brains. Given this observation, a symmetry detector was first constructed to automatically extract an iMSP – a virtual geometric plane about which the 3D anatomical structure captured in a brain image presents maximum bilateral symmetry (Liu, Collins, & Rothfus, 2001). Using the iMSP for pathological brain alignment for comparison, asymmetrical regions were detected automatically as possible lesions (e.g., bleeds, stroke, and tumors). A set of relatively simple and computationally inexpensive statistical image features were then collected to quantify and capture the statistical distribution differences of various brain asymmetries. For each image, a feature vector with 48 image features was constructed and used in the retrieval of similar pathological brain images.

Guimond, Subsoly, and Thirion (1997) introduced the use of a user-defined volume of
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