Dynamic Features refer to:

A.countor	EMM model parameter A
alpha.countor	EMM model parameter alpha
beta.countor	EMM model parameter beta
iAUC1.countor	V.1 feature (white paper)
Slope_ini.countor	V.2 feature (white paper)
Tpeak.countor	V.3 feature (white paper)
Kpeak.countor	V.5 feature (white paper)
SER.countor	V.4 feature (white paper)
maxCr.contour	III.2 feature (white paper)
peakCr.contour	IIII.3 feature (white paper)
UptakeRate.contour	IIII.4 feature (white paper)
washoutRate.contour	IIII.5 feature (white paper)
maxVr.contour	IV.4 feature (white paper)
peakVr.contour	IV.5 feature (white paper)
Vr_increasingRate.contour	IV.6 feature (white paper)
Vr_decreasingRate.contour	IV.7 feature (white paper)
Vr_post_1.contour	IV.8 feature (white paper)
minFri	Min iV.3
maxFri	Max IV.3
meanFri	Mean of IV.3
varFri	Variance of IV.3
skewFri	Skew of IV.3
kurtFri	Kurtosis of IV.3
iMaxVarianceuptake	IV.1
iiMin_change_Variance_uptake	IV.2
iiiMax_Margin_Gradient	I.1
k_for_Max_MarginGrad	k post of I.1
ivVariance	I.2

Notes: features on blue are also extracted from the inside voxels of the lesions (e.g A.inside)

Morphological Features refer to:

circularity	I.3
irregularity	I.4
edge_sharp_mean	From Levman et al. [1][8]
edge_sharp_std	From Levman et al. [8]
max_RGH_mean	Mean of I.5
max_RGH_mean_k	K post of I.5
max_RGH_var	Variance I.5

max_RGH_var_k	K of maxVar of I.5

Textural Features refer to:

"texture_contrast_zero" "texture_contrast_quarterRad" "texture_contrast_halfRad" "texture_contrast_threeQuaRad" "texture_homogeneity_zero" "texture_homogeneity_quarterRad" texture_homogeneity_halfRad" "texture_homogeneity_threeQuaRad" "texture_dissimilarity_zero" "texture_dissimilarity_quarterRad" "texture_dissimilarity_halfRad" "texture_dissimilarity_threeQuaRad" "texture_correlation_zero" "texture_correlation_quarterRad" "texture_correlation_halfRad" "texture_correlation_threeQuaRad" "texture_ASM_zero" "texture_ASM_quarterRad" "texture_ASM_halfRad" "texture_ASM_threeQuaRad" "texture_energy_zero" "texture_energy_quarterRad" texture_energy_halfRad" "texture_energy_threeQuaRad"	Refers to texture features at different orientations O=[0,pi/4,pi/2,3pi/4] Based on literature definition of **on GLCM texture Haralick et al.**

Labels:

```
table(set$BenignNMalignAnt)
```

```
   massB     massM  nonmassB  nonmassM
      69       104        31        39
```

Time-intensity 3 parameter Empirical Model Fit proposed in [2]

The following model can be used to describe the lesion contrast uptake and washout and to fit the data:

$$\Delta S(t) = A \cdot (1 - e^{-\alpha t}) \cdot e^{-\beta t},$$

Where **A** is the upper limit of the signal intensity, **alpha(min^{-1})** is the rate of signal increase, **beta(min^{-1})** is the rate of the **signal decrease during washout**. The goodness of fit parameter R^2 will be calculated for each lesion.

#	Feature name	Description	Requires	Intuition
V.1	**Initial area under curve (AUC)** [2]	$\mathrm{AUC}_\tau = A \cdot [(1 - e^{-\beta\tau})/\beta + (e^{-(\alpha+\beta)\tau} - 1)/(\alpha + \beta)]$, where tao is the time over which signal intensity is taken.		
V.2	**Initial slope of enhancement (Slopeini)** [2]	$Slope_{\mathrm{ini}} \approx A\alpha.$ Iitial slope of the kinetic curve can be calculated by taking the derivative of **AUC**		
V.3	**Time to peak of enhancement (Tpeak)** [2]	$T_{\mathrm{peak}} = \frac{1}{\alpha} \log\left(1 + \frac{\alpha}{\beta}\right).$ The time at which the kinetic curve reached peak Taken from setting the derivative of AUC equal to zero.		
V.4	**Signal enhancement ratio (SER)** [2]	$SER = \frac{\Delta S_1}{\Delta S_L} = \frac{1 - e^{-\alpha t_1}}{1 - e^{-\alpha t_L}} \cdot e^{(t_L - t_1)\beta},$ The signal intensity change at the **first timepoint** (delta S1) relative to the **last timepoint** (delta SL):		
V.5	**Enhancement curvature at peak (kpeak)** [2]	$\kappa_{peak} \approx -A\alpha\beta.$ The curvature at the peak of enhancement was calculated from the definition of curvature formula at time of Tpeak		

Enhancement-kinetics features

#	Feature name	Description	Requires	Intuition
III.1	Definitions: contrast enhancement & average enhancement [3]	$C(\mathbf{r},i) = \frac{S(\mathbf{r},i) - S(\mathbf{r},0)}{S(\mathbf{r},0)}, \quad i = 0,1,\ldots,5.$ In special circumstances this relation approaches linearity. $\bar{C}(i) = \frac{1}{L}\sum_{r=1}^{L} C(\mathbf{r},i), \quad i = 0,1,\ldots,5,$	**S(r,i) as the voxel value**	related to Gd-DTPA concentration in the extracellular space of breast tissue at **voxel r**.

III.2	**maximum uptake (FII,1)** [3]	$F_{II,1}=\max_{i=0,1,\ldots,5}\bar{C}(i).$	contrast enhancement & average enhancement	
III.3	**peak location (FII,2)** [3]	time frame index at which the maximum enhancement occurs	contrast enhancement & average enhancement & maximum uptake	
III.4	**uptake rate (FII,3)** [3]	$F_{II,3}=F_{II,1}/F_{II,2}.$		
III.5	**washout rate (FII,4)** [3]	$F_{II,4}=\begin{cases}\dfrac{F_{II,1}-\bar{C}(5)}{5-F_{II,2}} & (F_{II,2}\neq 5)\\ 0 & (F_{II,2}=5)\end{cases}$		

Enhancement-variance dynamic features

#	Feature name	Description	Requires	Intuition
IV.1	Max inhomogeneity of contrast uptake [4]	$\max_{i=0,\ldots,M-1}\left\{\dfrac{\text{variance}_{\mathbf{r}}F_l(\mathbf{r},i)}{\text{variance}_{\mathbf{r}}F_l(\mathbf{r},0)}\right\}$ runs **from frame 0** (before injection of contrast) **to M-1** (M is the total number of time frames)	set of voxel values in the lesion at time frame ‘’i’’ is given by **F_l(r,i)**, where vectors r point to the lesion, and index ‘’i’’	
IV.2	Min variance of uptake, [4]	$\min_{i=0,\ldots,M-2}\left\{\dfrac{\text{variance}_{\mathbf{r}}F_l(\mathbf{r},i)}{\text{variance}_{\mathbf{r}}F_l(\mathbf{r},i+1)}\right\},$	**Variance F_l(r,i)** is the computation of the variance of the voxel values at all **r** in the lesion	
IV.3	**spatial variance of enhancement** [3]	$V(i)=\dfrac{1}{L-1}\sum_{r=1}^{L}[C(\mathbf{r},i)-\bar{C}(i)]^2, \quad i=0,1,\ldots,5$ Five features are derived from the enhancement-variance dynamics. The		describes the time course of the spatial variance of the enhancement within the lesion
IV.4	**maximum variation of enhancement** (FIII,1)	Maximum spatial variance of enhancement $F_{III,1}=\max_{i=0,1\ldots,5}V(i)$		
IV.5	**peak location (FIII,2) of enhancement**	time frame index at which the maximum variance occurs		
IV.6	**enhancement-variance increasing rate (FIII,3)**	$F_{III,3}=F_{III,1}/F_{III,2}$		how fast the enhancement-variation within the lesion reaches maximum

IV.7	**enhancement-variance decreasing rate (FIII,4)**	$F_{III,4}=\begin{cases}\frac{F_{III,1}-V(5)}{5-F_{III,2}} & (F_{III,2}\neq 5)\\ 0 & (F_{III,2}=5)\end{cases}$	how fast the enhancement-variance decreases from the maximum
IV.8	**Enhancement-variance at the first postcontrast frame (FIII,5),**	**V(1)**	reveals the uptake inhomogeneity at the early phase of uptake.

Feature name	Description	Requires	Intuition
3D Sharpness of lesion margin [4]	$\max_{i=0,\ldots,M-1}\left\{\frac{\mathrm{mean}_{\mathbf{r}}\lVert\nabla[F_m(\mathbf{r},i)-F_m(\mathbf{r},0)]\rVert}{\mathrm{mean}_{\mathbf{r}}F_m(\mathbf{r},i)}\right\}$ Fm is limited to a shell—three voxels thick—centered on the surface of the lesion.	$\nabla[F_m(\mathbf{r},i)-F_m(\mathbf{r},0)]$ is the set of voxel-value gradients at the margin of the suspect lesion in the difference images of time frame ''i'' and precontrast frame ''0.'' sharpness of the uptake of contrast is computed **at the lesion margin.**	
3D variance of margin gradient [4]	$\frac{\mathrm{variance}_{\mathbf{r}}\lVert\nabla[F_m(\mathbf{r},i)-F_m(\mathbf{r},0)]\rVert}{[\mathrm{mean}_{\mathbf{r}}F_m(\mathbf{r},i)]^2}$ Computation of the spatial gradient is accomplished in 3D by convolution with the components of a 3x3x3 **Sobel filter** in three orthogonal directions.	only computed from the subtraction frames of ''i'' and ''0'' where the margin **Sharpness of lesion margin** is maximum.	malignant lesions take up contrast agent in a less homogeneous pattern than benign masses

Morphologic features

#	Feature name	Description	Requires	Intuition
I.3	**3D Circularity** [4]	$\frac{\text{volume of lesion within sphere of effective diameter}}{\text{volume of lesion}}$	Volume of lesion and effective diameter	"Circularity" quantifies how well the lesion conforms to a spherical shape
I.4	**3D Irregularity** [4]	$1-\frac{\pi\cdot\text{effective diameter}^2}{\text{surface of lesion}}$ Effective diameter = $2\cdot\sqrt[3]{\frac{3\cdot\text{volume of lesion}}{4\pi}}$	Surface of lesion and effective diameter.	malignant lesions have less sharp boundaries and are more

	circularity and **irregularity** in 3D are computed in world coordinates— rather than in voxel coordinates—to account for anisotropic voxels.		irregularly shaped. ''irregularity'' indicates the roughness of the surface
I.5 radial gradient histogram (RGH) [4]	Dot product between **voxel-value gradients** and **lines intersecting a single point near the center of the suspect lesion** (lines in radial directions) histogram—quantifying the frequency of occurrence of the dot products		**Radial gradient analysis** indicates how well structures in a ROI extend in a radial pattern originating from the center of the ROI.
I.6 variance of RGH values. [4]	$\max_{i=0,\ldots,M-1} \{\text{variance}_p \underset{p>0}{H\ (p)}\}.$ $p = \frac{\lvert \nabla[F_b(\mathbf{r},i) - F_b(\mathbf{r},0)] \cdot (\mathbf{r}-\mathbf{r}_c) \rvert}{\lVert \nabla[F_b(\mathbf{r},i) - F_b(\mathbf{r},0)] \rVert \cdot \lVert \mathbf{r}-\mathbf{r}_c \rVert}$	**Fb** is set of voxel-value gradients in a rectangular box encompassing the suspect lesion with an additional margin of 3 voxels **normalized RGH**	The variance of RGH values is used to quantify the flatness of the RGH.
I.7 max standard deviation of RGH [3]			
I.8 Margin Sharpness [5]	$\frac{\overline{\mathrm{RSI}_{\mathrm{in}}(r_i, t) - \mathrm{RSI}_{\mathrm{out}}(n(r_i), t)}}{d}$ a function of position (ri) and time (t); **ri** is a voxel position marker in three-dimensional coordinates (the inner ring**); n(ri)** is the six-connect three-dimensional neighborhood. ; **tf** is the final time point of the examination **d** is the normalization term		

Texture Features – based on GLCM texture Haralick et al. [6] [7]

For an image of **G** gray levels**, the G×G gray level co-occurrence matrix** Pd for a displacement vector **d** is defined as follows: The **entry (i, j)of Pd** is the number of **occurrence of voxel-pair of gray levels i and j** whose spatial locations are a vector **d apart**. When normalized by the total counts, the **entry (i, j)of Pd,** denoted **as p(i, j),** represents the (empirical) **probability of occurrence of voxel pair of gray levels i and j** whose spatial locations are a vector d apart. For a particular **voxel (gray), it has 26 neighbors** of 1 voxel distance **d** in 13 independent directions.

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[1] J. E. D. Levman and A. L. Martel, “A margin sharpness measurement for the diagnosis of breast cancer from magnetic resonance imaging examinations.,” *Academic radiology*, vol. 18, no. 12, pp. 1577-81, Dec. 2011.

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